JOURNAL of the AIR POLLUTION CONTROL ASSOCIATION

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SCIENCE & TECHNOLOGY

Harry A. Belyea, a Canadian, APCA's New President (See page 251)

June 1960
Vol. 10, No. 3
Parts I, II

3

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A Bi-Monthly Journal
Devoted to
Air Purification

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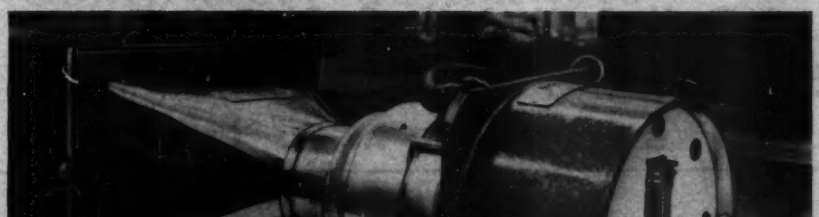

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LETTERS to the EDITOR

International Commission

Editor:

As you may know, as a result of our International Conference in October last, we are looking into the possibilities of strengthening international co-operation in the field of air pollution and its prevention. I knew that your own Association was also looking into this question, and have recently had a letter from Mr. Purcell of the County of Allegheny referring to this, and suggesting that you would be able to give me more information on what was being done.

I should therefore be very pleased indeed to hear from you about your own inquiries and the kind of organization that you have in mind or might be able to envisage being developed. We have not yet gone very far in the matter and there do seem to be considerable difficulties, except perhaps along the line of information exchange. The World Health Organization is also looking into the possibilities of strengthening international liaison in this field of work, but this presumably will have the most emphasis on the health aspects.

One of the difficulties seems to be the disparity between the different bodies and centers in different countries. I shall, of course, be glad to keep you informed of anything we may consider, or any action we may be contemplating, and I hope that we will be able to maintain contact in our explorations.

We greatly valued the presence of some of your colleagues at our Conference last October, which they helped and strengthened in many ways. As you may have gathered, we were rather overwhelmed by the response to this, both in the number of overseas delegates and in the number of papers that were sent in. We have not yet entirely recovered, but the final volume of "Proceedings" is in hand and should be published within two or three months.

ARNOLD MARSH
Director
National Society for Clean Air
London, England

Editor:

Your idea on an international commission of air pollution control is very clever, prudent, and opportune. Air over the globe especially that covers industrial countries are going to stain

(*Continued on next page*)

EDITORIAL

International Flavor

Although this editorial was written a month prior to the Annual Meeting, every indication at that time was that the 53rd Annual Meeting in Cincinnati would be one with considerable international flavor. Several Western German industrialists, in this country for visits to air pollution control agencies and installations, were contemplating the Annual meeting. Dr. Andre Roussel, here to study air pollution control programs under an Eisenhower Exchange Fellowship for a period of one year as one of the guiding lights of the new French Air Pollution Prevention Association, was also registered. In addition to these international visitors, other registrants were expected from as far away as Australia.

If these registrants were not enough to indicate the international character of the Air Pollution Control Association, the election of Harry A. Belyea, a Canadian, as President of the Association puts additional emphasis on the international aspects of APCA. Our membership directory lists members in Australia, Egypt, England, France, Germany, Italy, Japan, Mexico, the Netherlands, South Africa, Sweden, Switzerland, and Venezuela. We have obtained many new members from other foreign countries since publication of the directory.

Walter Wagner Sparks Idea

The late Walter C. Wagner of the Philadelphia Chamber of Commerce spark plugged the idea of an International Commission on Air Pollution, and in 1955, working as chairman of a special committee composed of nine past presidents of APCA and later also with H. M. Pier, Executive Secretary, prepared statutes for the international commission. The nature of the organization proposed in these statutes was this: the International Commission on Air Pollution would be a voluntary, co-operative nonprofit international forum to provide for the advancement and promotion of knowledge of air pollution and its control by the effective interchange, through correspondence, of scientific and technical information relating to research developments and applications.

The special task force presented a report to APCA's Board of Directors on October 14, 1957. This was the result of two years of effort which resulted in voluminous correspondence between Walter C. Wagner and outstanding scientists interested in the field from all over the world. In its summary to the Board of Directors of APCA, the special task force said "Our Association's leadership, now recognized throughout the entire technical world, both here and abroad, would render a positive disservice to progress unless it assumes the leadership in this definite responsibility." The APCA Board of Directors re-affirmed its policy by unanimously passing a motion at its May 25, 1958, meeting accepting the work of the committee that the formation of an international commission be pursued further by placing it on subsequent agenda.

Formation of such an organization takes a considerable length of time. It is not easy. However, a letter to the editor appearing in this JOURNAL from Arnold Marsh, Director and Secretary of the National Society for Clean Air of England surely indicates his particular position and that of his Society. The other letter from Takahide Taga, Chief Director and Executive Secretary of the Kanto-Shin-Etsu Heat Control Society of Japan clearly indicates the interest which he has in the formation of an international commission. Every effort shall be made from headquarters to promote the formation of an international commission in accordance with the Board policy. APCA's leadership in this, as well as the other aspects of the field of air pollution control, must be demonstrated.

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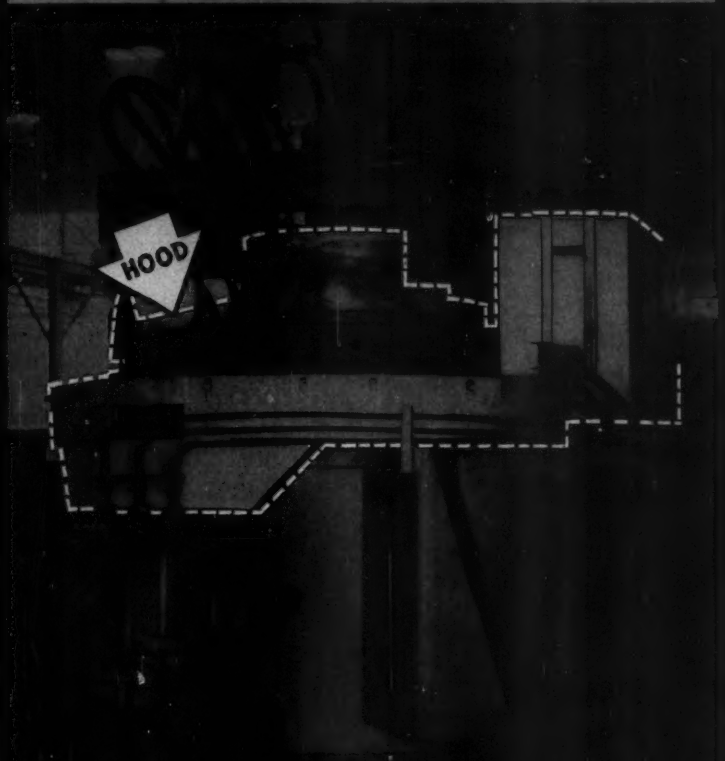

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(Continued from page 181)

year after year. The main reason of the stagnance comes from the gigantic development of industries to meet natural or, I might say selfish growth of human beings. If we leave them as they are, i.e., free competition of production without considering its effect upon our surroundings, the purpose of promoting our standard of life might be cancelled morally with the increase of nuisance around our daily life. We could say that we are hastening to our final goal, the death, purposely shortening or fouling the passage of polluted air. Is this the way that civilization should be?

Things seem to have been left unheeded too long. Now, the time has come to lay our hands together on them, quite aloof of borders and nationalities, for the sake of improving our surroundings as well as promoting happiness of those coming after us.

Your idea is very much appreciated and I will do my best, within my ability and convenience, to help you take steps.

TAKAHIDE TAGA
Chief Director
The Kanto-Shin-Etsu Heat Control Society
Bunkeyo-Ku, Tokyo, Japan

Atmospheric Pollutants Under Study at IIT

Atmospheric pollutants and their relationship to respiratory infections are being studied by scientists at Armour Research Foundation of Illinois Institute of Technology. Sponsored by the Air Pollution Medical Program of the U. S. Public Health Service, the program at present is concerned only with effects from gaseous pollutants, according to Dr. Richard Ehrlich, supervisor of biological research.

The study is designed to determine whether or not pollutants, such as ozone, sulfur dioxide, nitrous oxides, and hydrocarbons commonly found in community atmosphere affect the resistance to respiratory infections, such as pneumonia.

In this program a team of ARF scientists under Sol Miller, research bacteriologist, is exposing mice to an atmosphere containing individual gaseous pollutants. Some of the mice have been exposed to an airborne, pneumonia-causing bacteria, *Klebsiella pneumoniae*, before placement in the polluted atmospheres, others exposed to the disease-producing bacteria afterward. In this way, the scientists are able to note the effects of atmospheric pollutants on the laboratory animals both before and after exposure to the respiratory infection.

MODIFICATIONS *to* REDUCE EMISSIONS *from a Flue-Fed* INCINERATOR*

E. R. KAISER, Senior Research Scientist and **J. HALITSKY,** Research Scientist of New York University; **M. B. JACOBS,** Director of Bureau of Laboratory and **L. C. McCABE,** Consultant and Project Director, Department of Air Pollution Control, City of New York

Since January, 1957 New York University has conducted a research program to reduce air pollution from flue-fed incinerators of the type commonly used in apartment buildings. The program has been supported by research grants from the National Institutes of Health, U. S. Public Health Service.

The primary objective of the program is to develop and evaluate by field tests various modifications to existing incinerator installations that will reduce the emissions of particulate matter, noxious gases, smoke, and odor to the atmosphere. A secondary objective is to obtain data and experience to guide the selection of incinerator features for new installations.

Flue-fed incinerators, with charging hoppers on each occupied floor, are a convenience to the tenant, and reduce the weight and volume of refuse to be removed from the premises. Such incinerators are widely used throughout the country. Approximately 11,000 flue-fed incinerators, which are estimated to burn 600,000 tons of refuse annually, are in use in New York City alone. Incinerators to dispose of garbage and other waste matter are required by law in New York City for multiple dwellings of four or more stories occupied by more than 12 families and erected after October 1, 1951. Nevertheless, to reduce air pollution some cities have adopted restrictions against new installations.

Of the total number of complaints of air pollution received by the Department of Air Pollution Control in 1957, approximately one-fifth were directed against incinerators. The complaints were caused by particulate matter, smoke, and odor in that order. The emissions from incinerators are reported to be a major source of air pollution in the vicinity of apartment buildings, particularly in the highly populated areas.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 22–26, 1959, Los Angeles, Calif.

The first report of the project described the performance of a typical single-chamber, flue-fed incinerator and the manner of its normal operation in a 16-story apartment building in New York City.[1] The emissions of particulate matter, noxious gases, smoke, and odor had been determined to provide a basis for comparison with similar measurements when the same or identical incinerators were modified to reduce the emissions.

The present report indicates what reductions in emissions may be expected in practice by the use of various devices that can be added to existing installations.

The criteria for selecting the devices evaluated were: (1) adaptability to existing single-chamber, flue-fed incinerators, (2) simplicity of operation, (3) reduction of air pollution, particularly neighborhood nuisances, (4) durability and low maintenance, and (5) reasonable investment and operating costs.

Because the tests were limited to one size of incinerator and were limited by other field conditions, tests should be regarded as indicative and relative, and by no means exhaustive.

Basic Incinerator, Flue, and Cycle

The tests were conducted on the incinerators in three buildings of a nine-building group of the Fordham Hill Apartments, Borough of Bronx, New York City. Each building had 128 apartments totaling 511 rooms on 16 floors, with a total occupancy of 295 to 305 persons. The buildings and incinerators were identical for all practical purposes. The unmodified installations consisted of furnaces as shown in Fig. 1. A 27 x 27-in. brick flue extended from the right rear corner of each furnace roof a distance of 189 ft to a "spark arrester" screen 43 ft above the building roof. The incinerators were located in interior basement rooms provided with air

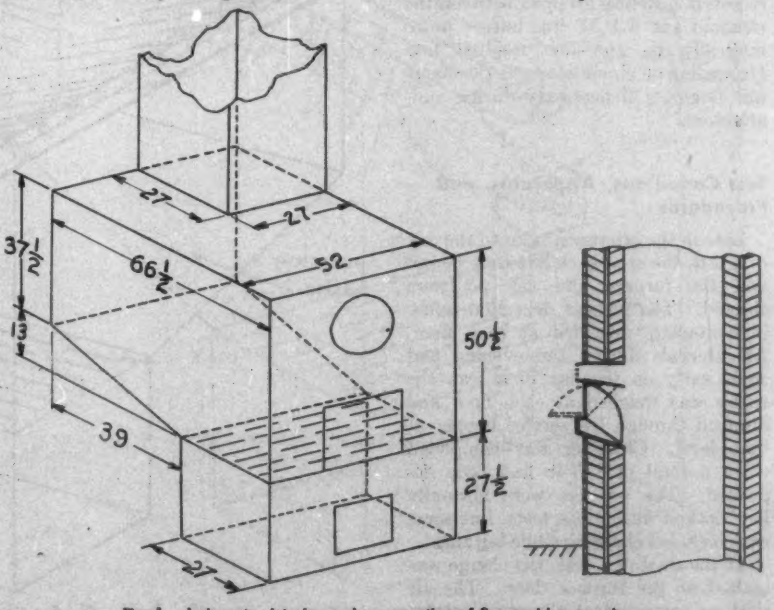


Fig. 1. Incinerator interior and cross section of flue and hopper door.

supply ducts to the outside.

The illustrated service doors (hoppers) into the flues were located in closets on each of the 16 occupied floors. The closets were normally unlocked and refuse could be dropped into the incinerators at all hours. A considerable amount of air entered the flue by leakage around the service hoppers and through louvers cast in the service-door frames of the lower 8 floors. The area of the cast openings was 144 sq in., and the air leaking into the flue was approximately four times the amount of air that entered the furnace.

The charging during a typical day is graphed in Fig. 2. Most but not all of the loose refuse was in paper bags or wrapped in newspaper. The refuse included garbage, tin cans, bottles, rags, sweepings, wire coat hangers, wrappings, etc., but few newspapers unless used for wrapping refuse.

In conformity with local regulations, any fire left in the incinerator was extinguished by 5 P.M. The refuse dropped between that hour and 8 A.M. the following morning, about 275 lb, normally produced a compacted pile of heavy refuse under the flue to the height of the furnace roof. Some material had also rolled to the other areas of the hearth and grate. The top of the charge was predominantly paper. Cartons and other refuse were also charged through the furnace door by the building porter.

The charge was normally ignited between 8 and 8:30 A.M. and allowed to burn unattended until 10 to 11 A.M., when the attendant raked the remaining refuse forward off the rear hearth to the grate. A vigorous resumption of combustion ensued. After near completion of the burn, the residue was removed. Refuse dropped between the cleanout and 5 P.M. was burned automatically on the low residual fire. Depending on circumstances, the charge was reignited if necessary during mid-afternoon.

Test Conditions, Apparatus, and Procedures

Late in the afternoon prior to the day of a test, the service closets were locked and the furnace and ash pit were cleaned. The tenants deposited refuse in containers provided at each floor. At intervals during the evening and again early on the day of a test, the refuse was weighed at each floor and dropped through the service hopper at that level. Charging was completed when a total of 275 lb had been deposited. The hoppers were normally kept locked during the tests, but some runs included charging while burning.

At the start of a test, the charge was ignited at the furnace door. The air shutters remained at the same setting throughout the burn except as will be indicated for the Werner Device. The charge was raked forward once during the burn when flaming had nearly ceased. The tests were terminated when the operator noted the lack of flame. However, the dust sampling of the flue gas was continued during the removal of the residue following the termination of combustion. Light water quenching was used on any material that rekindled when the residue was being removed.

A detailed description of the test apparatus and procedure was given in the previous report.[1] Briefly, gas temperatures, drafts, and velocities were measured in the furnace, lower flue, and upper flue. The furnace thermocouple junction was located 1 ft in each direction from the upper right corner of the furnace. Gas samples were taken continuously for determination of aldehydes, ammonia, organic acids, esters, nitrogen dioxide, phenols, and sulfur dioxide. Particulate matter in the flue gas was sampled isokinetically in the center of the flue at the 16th-floor level and collected in filter thimbles, followed by wet impingers. Smoke in a 2-ft column of flue gas from the upper flue was observed continuously by a photo-electric meter.

A von Brand filtering recorder was used to measure the "quantity of reflectance units of dirt shade"[2] or area-covering blackness in a unit volume of

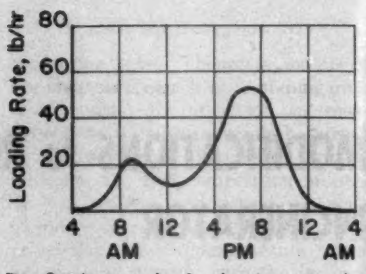


Fig. 2. Average hourly charging rates by tenants. Total of 430 lb or 1.44 lb daily per tenant.

flue gas. The results were expressed as Q-Ruds per lb of gasified charge. Odor in the flue gas was determined by the ASTM Tentative Method (1956) and was expressed in concentration units equal essentially to the volumes of air necessary to dilute the flue gas to below the limit of perception. Further details and results are included in the sections on each type of incinerator modification.

Overfire Air Jets

The roles of underfire and overfire air in the combustion of refuse and other solid fuels have been recognized for many years. Undergrate air is necessary in incinerators to expedite the combustion of the refuse below the layer that can be reached by overfire air, particularly during the latter half of the burn when cans, bottles, and ash,

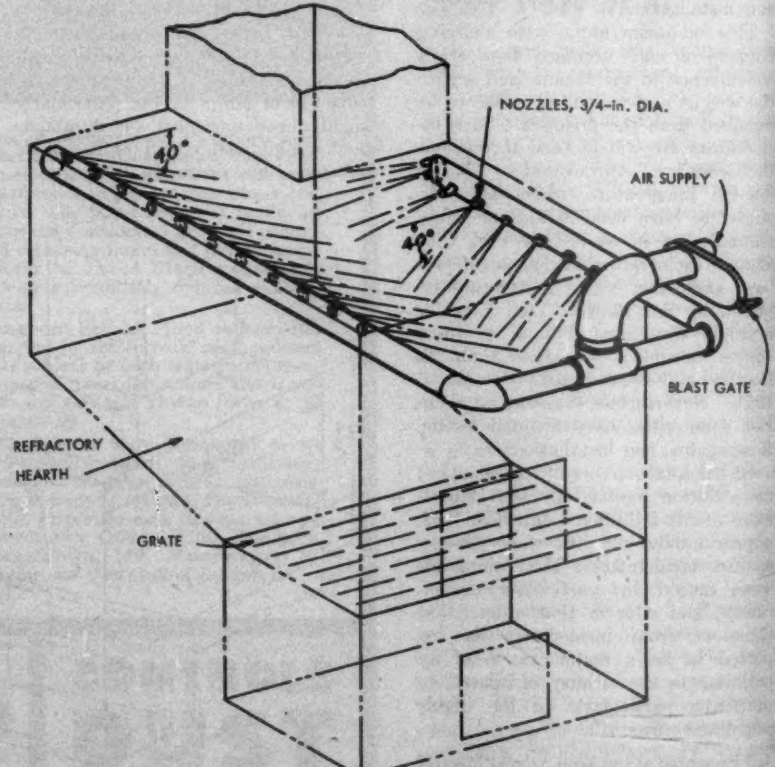


Fig. 3. Overfire air manifolds, arrangement A.

cover the burning charge. Air is necessary over a deep fuel bed or charge to consume the combustible gases and unburned particles that are released in those zones of the charge where air supply and/or temperature are insufficient. The overfire air must be intimately mixed with the gasified fuel to be effective. A rich mixture of fuel in limited air exists in the refuse charge at the early stages of a burn when the ignition plane is progressing through the material.

Rose and Crabaugh[3] have reported a decrease of contaminants of 35 to 50% where overfire air is the predominant source of combustion air. Overfire air jets have been used effectively for years to reduce smoke in bituminous-coal-fired boilers. Specific instructions for sizing and locating the jets have been published.[4]

Two separate arrangements of overfire air nozzles were tested to provide increased turbulence near the top of the burning refuse, so as to promote more complete combustion of suspended particles and gases. It was hoped that impingement of the air on the burning charge would also hasten its combustion and increase furnace temperatures, at least during part of the cycle. Arrangement A (Fig. 3) consisted of two standard 4-in. mild-steel pipe manifolds entering the furnace through holes cut in the front wall immediately below the furnace roof and tangent to the side walls. The overfire manifolds occupied unused space in the furnace and thus did not affect the furnace volume available for the charge. The manifolds were supported on the front wall and by pipe hangers at the ends in the furnace. The manifolds were joined to a 6-in. pipe header from a blower. The header was provided with a measuring orifice and blast gate.

The longer (left) manifold had 10 openings, 3/4 in. diam, spaced 6 in. apart and directed downward 40° from the horizontal plane and perpendicular to the manifold. The right-hand manifold was shorter because of the flue and had only nine openings, 3/4 in. diam, seven of which were angled 40° downward like those of the opposite manifold, which two holes were directed toward the space under the flue. The pipes showed no evidence of scaling or deterioration despite the fact that they were purposely subjected to the incinerator heat for months without benefit of air cooling except on test.

Following beneficial results from the use of overfire air by Arrangement A, a simpler, one-pipe overfire manifold B was substituted for it, as shown in Fig. 4. The 5.5-in. mild-steel tube had 18 ports drilled 3/4 in. in two rows, and directed downward 60° from the horizontal plane. The distance between pairs of holes was 6 in. The pipe was closed at the far end and supported by a pipe hanger, although a slightly longer pipe might have been supported in a hole in the brickwork of the rear wall. The outside end of the pipe was connected to the blower discharge. No measuring orifice was provided as the air flow had been determined independently as a function of pressure differential across the ports. Figure 5 illustrates the location of arrangement B in the furnace.

With arrangements A and B, the overfire blowers were operated from light-off to quench. The blowers were not operated during ash removal. The ports in the air shutters of the furnace and ash doors were fixed at 2.6 and 5.2 sq in respectively, the same as in tests of the basic incinerator.

The improvement in performance is shown by the reduction in emissions in Table I.

The atmosphere in the furnace was uniformly clearer when the jets were in use. The peak temperatures in the furnace were 140 to 370°F higher generally when overfire jets were used. The average furnace temperatures were also higher because of more rapid combustion (shorter burning time) and correspondingly less excess furnace air.

Both overfire jet systems improved the performance of the incinerator.

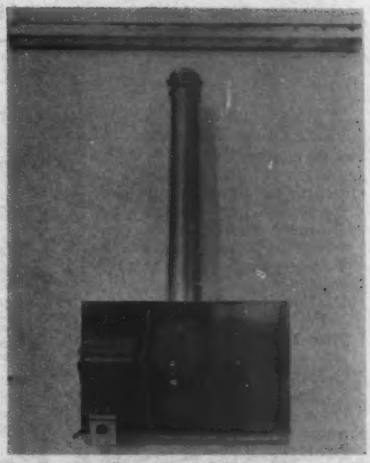


Fig. 4. Overfire air manifold and blower, arrangement B. Lower side of manifold shown at top.

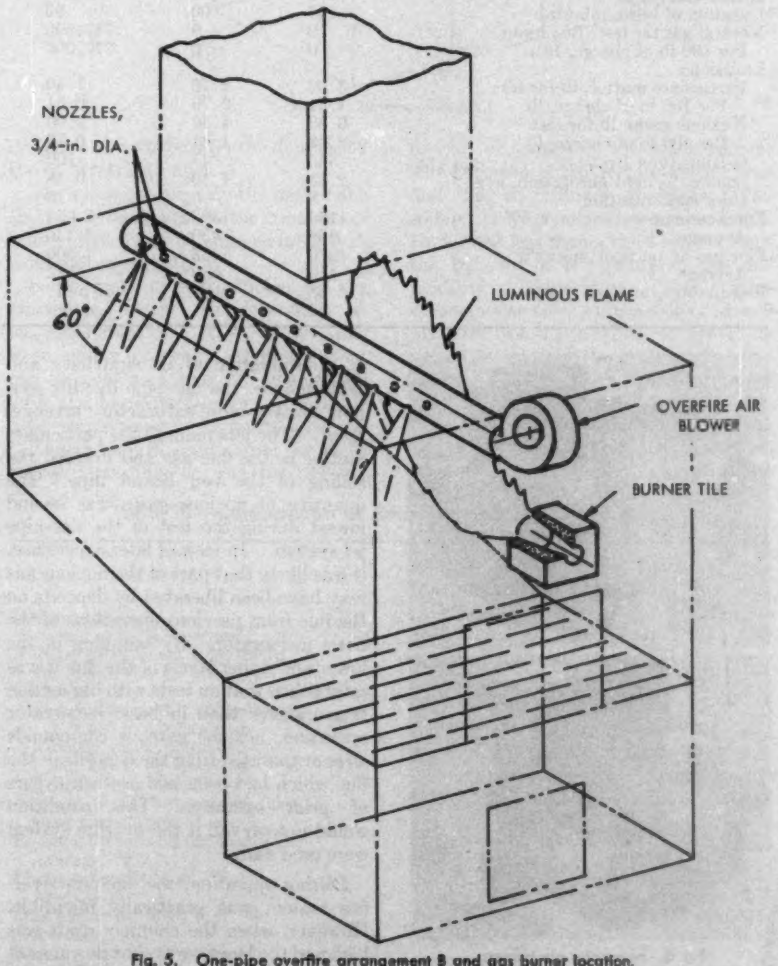


Fig. 5. One-pipe overfire arrangement B and gas burner location.

Table I—Comparison of Emissions—Overfire Air Jets

	Basic Incinerator	With Overfire-Jet Arrangements A	B
Refuse charge, lb	275	275	275
Duration of burn, minutes	117	105	90
Overfire jets, lb air per hr, avg	0	804	640
Percent of total furnace air	0	10	8.6
Blower output, cfm	—	178	142
Manifold pressure, in. wc	—	0.45	0.74
Furnace draft, in. wc avg	0.4	0.5	0.57
Emissions			
Particulate matter, lb for test	3.62	3.01	2.18
Per 100 lb of charge, lb	1.31	1.09	0.79
Noxious gases, lb for test	6.83	3.89	4.43
Per 100 lb of charge, lb	2.48	1.41	1.61
Q-Ruds (von Brand)	855	460	345
Smoke, % light absorption, avg	2.81	1.27	1.10
Odor concentration	8	7	—
Furnace temperature, max., °F	1160	1300	1530
Average, °F	488	507	630
Flue gas at 1st floor, max., °F	1270	1410	1483
Average, °F	450	495	589
Residue wgt, in % of charge	38	36	37

Table II—Comparison of Emissions—Auxiliary Gas Firing

	Basic Incinerator	One-Pipe Overfire Air Jets	Gas Burner and One-Pipe Overfire Air Jets (B)
Refuse charge, lb	275	275	275
Duration of burn, minutes	117	90	85
Natural gas for test, Btu input	0	0	743,600
Per 100 lb of charge, Btu	0	0	270,000
Emissions			
Particulate matter, lb for test	3.62	2.18	1.40
Per 100 lb of charge, lb	1.31	0.79	0.51
Noxious gases, lb for test	6.83	4.43	2.00
Per 100 lb of charge, lb	2.48	1.61	0.73
Q-Ruds (von Brand)	855	345	100
Smoke, % light absorption, avg	2.81	1.10	0.18
Odor concentration	8	—	10
Furnace temperature, max, °F	1160	1530	1,655
Average, °F	488	630	1,146
Flue gas at 1st floor, max, °F	1270	1483	1,500
Average, °F	450	589	822
Residue wgt, in % of charge	38	37	35 and under

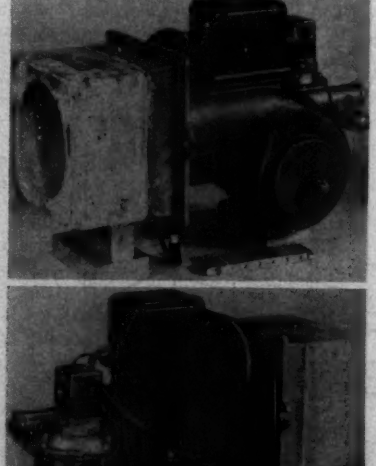


Fig. 6. Incinerator gas burner.

In consideration of its simplicity and performance, the one-pipe overfire system was the more satisfactory arrangement. The jets reduced the particulate matter in the flue gas and lowered the soiling of the von Brand tape. The quantity of noxious gases was second lowest during the test of the one-pipe jet system. In view of later experience, it was likely that part of the noxious gas may have been liberated by deposits on the flue from previous operations of the basic incinerator. By sampling in the lower and upper levels of the flue it was established that on tests with higher flue temperatures than in basic incinerator operation, noxious gaseous compounds were evaporated from the deposits in the flue which had been laid down by years of prior operation. This condition would not prevail if the overfire system were used daily.

During operation, the one-pipe overfire system was practically inaudible. However, when the chimney draft was high and the blower was shut down, as at the end of a burn, the jet manifold emitted a low-pitched tone of moderate intensity. The tone was eliminated by closing the blower inlet, although 90% closure was almost as effective. Simple yet automatic means for preventing this organ-pipe effect could be devised.

Auxiliary Fuel Firing

The presence of unburned gases and carbonaceous particles in the flue gas, despite the presence of a high excess of turbulent air in the furnace, indicated the need for additional furnace temperature. Theoretically, a reduction in excess overfire air would elevate the combustion temperatures, but the rate of burning would also decrease in the incinerator. The cold furnace surfaces and the moisture in the charge also absorbed considerable heat.

To supply additional heat a standard gas-fired incinerator burner with integral blower and controls was installed centrally on the front wall of the incinerator in the space available between the furnace doors and the one-pipe overfire system, as shown in Fig. 5. The burner, electric igniter, controls, burner tile, and other features are shown in Fig. 6.

The gas orifice was arbitrarily adjusted to deliver approximately 525,000 Btu of natural gas per hour. The air damper on the blower inlet was adjusted to maintain a flame from the front wall to the entrance to the flue, about 4 ft. In the absence of premix of gas and air the flame was highly luminous, which was desired for maximum radiation to the charge and the suspended particles.

The air shutters on the furnace and ash doors were left fixed at the same openings as in the tests of the overfire jets. The one-pipe overfire-jet arrangement was operated in conjunction with the gas burner to provide turbulence in the furnace. The overfire blower was turned on when the charge was ignited, and the gas burner was turned on shortly after.

The sampling of the flue gas for noxious gas was conducted in the lower flue (first floor level) and at the 16th floor. As a considerable amount of noxious gas from operation of the basic incinerator was distilled off the inside of the flue at the elevated temperatures obtained by gas firing, the amount of noxious gas in the lower flue is reported. By daily use of the auxiliary burner on a converted incinerator, the flue would eventually lose deposits that volatilize under the new temperature conditions.

The results of the tests are summarized in Table II.

The combination of auxiliary gas firing and one-pipe overfire-air system reduced the emissions from the furnace to the lowest level of all arrangements

tested. The increased furnace temperature and the radiation from the gas flame promoted completeness of combustion and reduced the burning time. The furnace surfaces, which were black from carbon deposits in the basic incinerator, were largely restored to their original firebrick color when gas firing was used. The flame radiation to the residue also helped to reduce the quantity of unburned char present with the noncombustibles at the end of a burn. More white ash was present on the grate and in the ash pit than on runs with the basic incinerator or with overfire jets. Conversely, for the same quality of residue as from the basic incinerator, the operating time of the gas burner could have been reduced 10 to 15 minutes, with a proportional saving of gas and some reduction in fly ash.

The furnace atmosphere was unusually clear during operation with the gas burner. The flue was practically free of any smoke. The von Brand tape had only minor soil and the filter thimbles were cleaner than on other tests. The odor concentration in the flue gas was apparently not reduced by the gas burner, and may have been increased slightly. The difference was within the error of measurement.

Hartmann Device

A novel design of gas-fired secondary combustion chamber inside a single-chamber incinerator was proposed by Henry Hartmann of Amityville, Long Island. Fabricated by the R. G. White Manufacturing. Co., of Ozone Park, N. Y., the secondary combustion chamber and flue (flame tube), as well as an overfirejet manifold, were made of stainless sheet steel.

As illustrated in Fig. 7, a retractable steel plate was used to close the top of the furnace after a sufficient charge of refuse had accumulated. Of necessity the service hoppers must be locked when the top of the furnace is closed. A gas burner with integral blower was mounted on the furnace front on the axis of the flame tube. At the start of a test the burner was ignited to preheat the secondary chamber for two minutes, after which the refuse either ignited automatically or was kindled by the attendant. When the gas burner was the only source of heat, the gas temperature at the flame-tube exit rose to 825°F. The gas input rate was 275,000 Btu per hr. The gas burner produced a blue flame which became yellow when mixed with the products of combustion of the refuse.

The refuse was burned by undergrate and overfire air, the latter supplied to a manifold by a small blower and distributed over the top of the charge by 32 orifices. All products of combustion entered the flame tube through a coarse grille. Natural draft on the

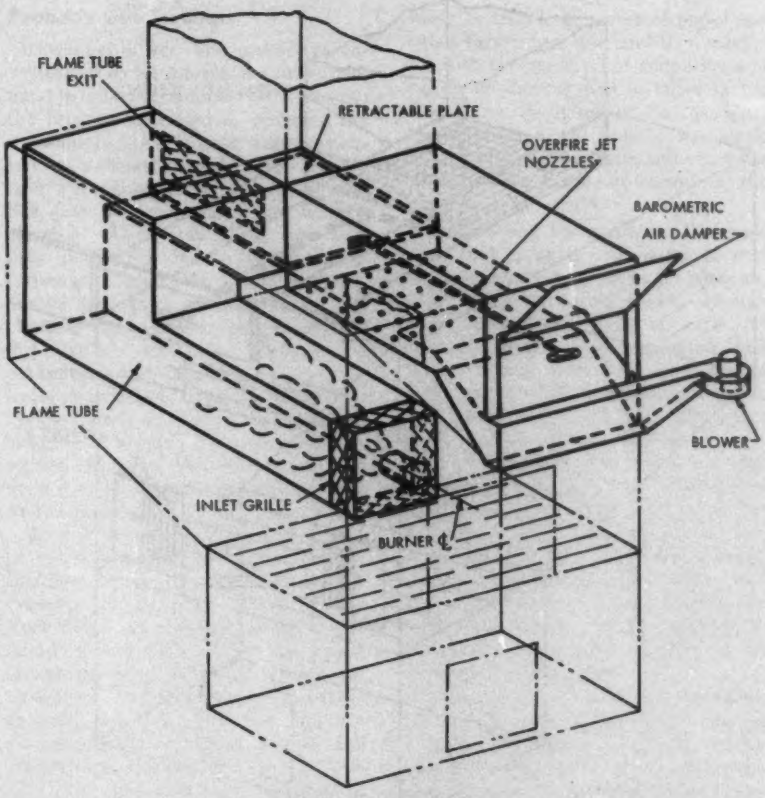


Fig. 7. Hartmann device.

system was controlled by the damper on the barometric air duct.

The space occupied by the flame tube and air ducts reduced the amount of refuse that could be charged to 200 lb from the original 275 lb.

Seven tests were conducted on the Hartmann Device to determine its characteristics. Of these, three tests were under practical conditions that can be used as a basis for comparison with the basic incinerator. The averaged results are summarized in Table III.

The absence of smoke from the stack was outstanding, as was the absence of bits of paper on the stack screen. The emission of particulate matter was half that in ordinary operation. The soiling property of the emission (Q-Ruds) was less than a third of that from the burning of the refuse in the unmodified incinerator. Low dust emission was partly the result of slower primary burning because of lower air velocities through the grate and partly because of secondary combustion of particles in the flame tube.

The presence of some noxious gases may be the result of rapid chilling of the burning natural gas during most of the

Table III—Comparison of Emissions—Hartmann Device

	Basic Incinerator	Hartmann Device
Refuse charge, lb	275	200
Duration of burn, minutes	117	120
Natural gas for test, Btu, input	0	557,000
Per 100 lb charge, Btu	0	278,500
Emissions		
Particulate matter, lb for test	3.62	1.45
Per 100 lb of charge, lb	1.31	0.72
Noxious gases, lb for test	6.83	3.49
Per 100 lb of charge, lb	2.48	1.75
Q-Ruds (von Brand)	855	237
Smole, % light absorption, avg	2.81	0
Odor concentration	8	6
Primary furnace temp., max., °F	1160	1,220
Average, °F	488	732
Flame-tube exit, max, °F	—	1,600
Average F	—	1,055
Flue gas at 1st floor, max, °F	1270	300
Average, °F	450	245
Residue wgt, in % of charge	38	36

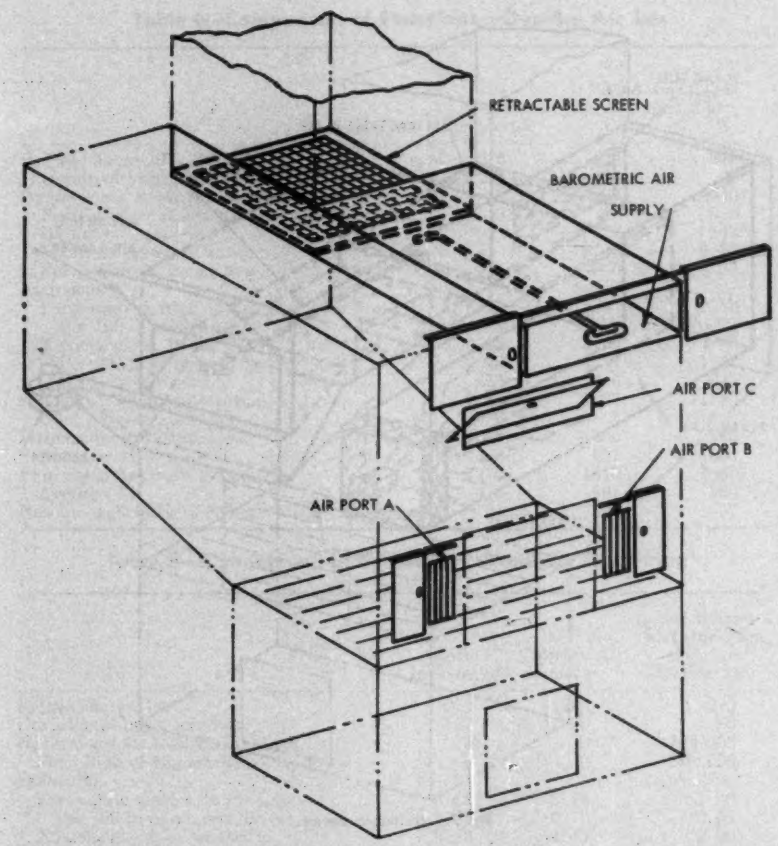


Fig. 8. Werner device.

burn by cool furnace gases. Organic acids, esters, and aldehydes in that order accounted for the unburned gases. This result is similar to that reported by Tebbens, et al.[5,6] Another possibility is that the products of the slower combustion in the primary chamber were not brought to sufficient temperature for complete combustion in the flame tube. For example, Underwood[7] reports that (coal) smoke burns in preference to methane and unsaturated hydrocarbons in the temperature range of 650 to 850°C (1202 to 1562°F). However, there was obviously enough heat to burn the smoke.

Noxious gases in the flue at the first floor level were reported in Table III. By the time they reached the 18th floor level, the noxious gases had increased to 4.20 lb per 100 lb of charge. It is believed that the additional gases not present at the first floor level were distilled from the walls of the flue. The odor concentration of the flue gases at the 18th floor level were somewhat lower with the Hartmann Device than with the basic incinerator.

The gas consumption per 100 lb of charge was almost identical to that for gas firing directly into the primary combustion chamber. The average temperature in the primary furnace was 414°F lower with the Hartmann Device than with direct gas firing. The maximum temperature on one test of 1600°F at the exit of the flame tube was reached during the rapid burning of the refuse paper shortly after light off, with another lower peak immediately after raking of the charge.

The low temperature in the flue was the result of cooling the products of combustion leaving the flame tube by the addition of a large volume of barometric air. Auxiliary fuel firing can thus be practiced without overheating the service hoppers and no special flue lining is required.

Werner Incinerator Device

To expedite the combustion of apartment refuse in a nuisance-free manner without auxiliary fuel firing, a set of modifications for the basic incinerator was conceived by Albert Werner, President, Werner Air Pollution Control, Inc., Brooklyn, N. Y. Eight tests were conducted on an installation at Fordham Hill Apartments.

The design features are illustrated in Fig. 8. Air for combustion was supplied to the furnace by natural draft through special ports A, B, and C, which had adjustable closures for air control as well as safety grilles. Air was also supplied through the ash pit and controlled by the ash door and its shutter. Another feature was the steel duct immediately under the furnace roof, which extended from the incinerator room to the base of the flue. The duct supplied barometric air to control the natural draft and provided an observation port and access to a retractable nichrome wire screen with 0.10-in. openings. The duct reduced the furnace capacity to 240 lb from 275 lb. Other special equipment, not shown, was a narrow slice bar that was inserted through ports A and B for gently lifting the burning refuse, and a water lance for spraying the nichrome screen from above.

Except during the burning periods, the screen was in the retracted position. When the charge was to be burned, the service hoppers were locked and the screen was pushed to the position shown. The screen was thus protected from the impact of falling refuse.

During the burning cycle of 20 to 22 minutes for a 240 lb charge, the ash door and all air ports were wide open most of the time. A roaring fire was maintained by slicing the fire and by raking the charge forward. All combustion gases passed through the screen, which glowed bright red much of the time. Many glowing particles were observed in the flames passing through

Table IV—Comparison of Emissions—Werner Device

	Basic Incinerator	Werner Device
Refuse charge, lb	275	240
Refuse gasified, lb	166	129
Duration of burn, minutes	117	21
Emissions		
Particulate matter, lb for test	3.62	3.10
Per 100 lb of charge, lb	1.31	1.29
Per 100 lb gasified charge, lb	2.18	2.40
Noxious gases, lb for test	6.83	7.23
Per 100 lb of charge, lb	2.48	3.01
Per 100 lb gasified charge, lb	4.11	5.60
Q-Ruds (von Brand)	855	307
Smoke, % light absorption, avg	2.81	0.71
Odor concentration	8	7
Furnace temp., max., °F	1160	1600
Average, °F.	488	872
Flue gas at 1st floor, max., °F	1270	420
Average, °F.	450	358
Residue wgt, in % of charge	38	46

the screen. Pieces of paper were retained on the underside of the screen until consumed. The fly ash that was retained by the screen so restricted the flow of gas and reduced the combustion rate that it was necessary to wash the screen three times during the burn.

To shorten the time of a burn and to reduce emissions up the flue, the fire was quenched while still flaming but when the volume of refuse had been reduced so as to consist mainly of noncombustibles. The reasons for early removal of the residue were: (1) to reduce the emissions to the flue, (2) to shorten the time required of the attendant, and (3) to shorten the period when the hoppers were locked. The operation depended on continuous attention by the operator and active manipulation of fire tools, lance, and dampers. The damp residue was removed promptly and the screen was retracted to permit unlocking of the service hoppers. In daily practice the service hoppers could thus be restored to use by the tenants in 30 to 35 min after locking.

The emissions to the atmosphere and other important data are summarized in Table IV.

The use of the nichrome wire screen prevented paper from being carried up the flue and thereby eliminated that nuisance. The soiling property of the emission was reduced to almost a third, no doubt the result of the higher temperatures. Although free carbon and tars in the flue gases were undoubtedly reduced by the Werner Device, this gain was offset by the increase in fly ash resulting from high velocities through the grate and furnace.

The total smoke and odor added to the atmosphere by the Werner Device was considerably less than that from the unmodified incinerator, not only because of reduced concentration but also because the total amount of flue gas during the test was half that of basic operation.

The effect of terminating the burning cycle before the normal end of a burn was not evaluated because no tests of the unmodified incinerator were terminated early. Certainly, less fly ash and noxious gas per 100 lb of charge would result from an early quench. Also, the wetter quench of an early termination would reduce the amount of fly ash carried up the stack during the residue removal. An approach to such a comparison was made in Table IV, by reporting emissions on the basis of lb of charge gasified. On that basis no improvement in emission of dust was made. The emission of noxious gases is reported for the 18th floor level of the flue. Because of the short time of a burn and the cooling effect of barometric air, it is unlikely that the amounts of noxious gases were affected unduly by distillation of old deposits.

Peabody Gas Scrubber

Cleaning of the flue gases was investigated as an alternative or supplement to improved combustion. Despite the progress indicated in reducing the emissions from the furnace, some particulate matter, noxious gases, smoke, and odor will still leave the furnace with the flue gases during burning and furnace cleaning. Also, some dust, lint, and light paper will fail to fall into the furnace because of the upward velocity always present in the flue. Two gas cleaning methods were considered, the dry cyclone and wet scrubber. A preliminary test of a dry cyclone collector showed deposition of fats on the cyclone surface, indicating eventual clogging in service. The wet scrubber[8] seemed to offer the better solution, since it would remove noxious gases as well as particles.

A gas scrubber, Size PSS3, was provided and installed in the Eton Building of the Fordham group by Peabody Engineering Corp., New York City. A suitable location was found on the floor above the upper tenant quarters, 146 ft above the incinerator. The arrangement for withdrawing gas from the flue and for discharging the scrubbed gas to the atmosphere is shown in Fig. 9. The 12 x 12-in. gas inlet was positioned in the center of the flue and protected by 9 sq ft of heavy steel screen of 1-in. mesh to trap large pieces of paper and other light refuse now and then carried up with the gases. For simplicity and safety no damper was installed in the flue. Free discharge of flue gas past the scrubber would thus be automatic in case of a power failure and when the peak gas flow was in excess of the capacity of the scrubber.

On entering the scrubber, the gases were first sprayed with water to cool the gases and to trap the larger particles, after which the gases passed through two impingement trays of water for intimate contact of impurities and water. Each tray had an area of 3.96 sq ft, with perforations $^{3}/_{32}$-in. diam on $^{3}/_{16}$-in. centers. The gases next passed upward through a 4-in. mat of stainless steel mesh to trap entrained water droplets. Ceramic Berl saddles were also used in place of the stainless mesh in several tests. The scrubber gases were exhausted through a centrifugal fan and a 10 x 10-in. duct to the outdoors. Tests were also run with the scrubber exhaust returned to the stack and directed upward by an elbow into a vaned diffuser.

Fresh makeup water was added to the upper tray at the fixed rate of 1 gpm. The water from the sprays and trays drained to the sump in the base of the scrubber, from which it was recirculated at 15–20 psig by a small centrifugal pump. The flue gas was

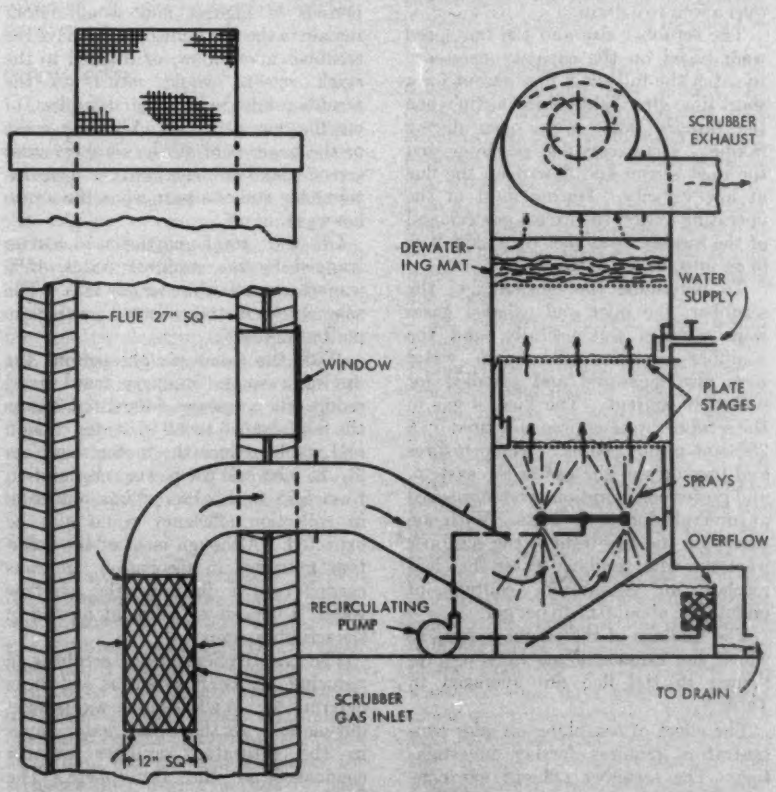


Fig. 9. Peabody gas scrubber.

Table V—Peabody Scrubber Performance

Refuse charge, lb per test	275
Scrubber operating time, minutes	96
Scrubber exhaust, avg cfm (corrected to 70°F, 29.92 in. Hg)	2670
Gas temperatures, °F	
Scrubber inlet, range	153–250
Average	196
Scrubber outlet, range	94–108
Average	102
Scrubber trays, number in use	2
Pressure across fan, in. wc	7.6
Electric consumption, fan kw	5.35
pump	0.4
Total	5.75
Scrubber water	
Input, gal/hr	60
Evaporated, gal/hr	24
To drain, gal/hr	36
Emissions	
Particulate matter, lb for test	
Collected by scrubber water, avg	1.88
In exhaust, avg	0.12
Total	2.00 lb
Scrubber collection efficiency, %	94
Noxious gases, lb for test, avg	
In flue gas before scrubber	8.83
In scrubber exhaust	6.92
Removed by scrubber, diff.	1.91 lb
Removal efficiency for noxious gases, %	21.6
Q-Ruds (von Brand)	
Flue gas before scrubbing	345
Flue gas after scrubbing	170

saturated with water vapor at the exhaust temperature by the evaporation of scrubber water; the loss of water was nearly 0.4 gpm. The excess scrubber water, 0.6 gpm, and trapped pollutants from the flue gases were discharged over a weir to a drain.

The scrubber size and the fan speed were based on the capacity necessary to catch the full stack flow except for a short time after light off and again when the furnace doors were open during raking. The excess flue gas by-passed the inlet screen and flowed up the flue at low velocity. During most of the operating period the excess gas demand of the scrubber was met by a slow flow of air into the top of the stack.

To determine the efficiency of the scrubber, the inlet and exhaust gases were sampled isokinetically, and the scrubber overflow and sump water were also measured and sampled for pollutant content. The flow of gas in the scrubber exhaust was measured by a 25-point pitot traverse. Temperatures and pressures of the gas in the system, and power consumption, were measured at intervals during the tests. With one exception the five tests of the scrubber were run with scrubber water that had reached an equilibrium content of pollutants, about 0.05 lb per gal.

The findings of the scrubber tests in which the exhaust gases were not returned to the flue are averaged in Table V.

The effect of scrubbing on odor concentration requires further investigation. The scrubber effluent gas contained odorants although the odor of the overflow water indicates that part of the odorant was trapped.

The scrubber was effective in preventing the carry-up of paper to the stack screen. Any paper that might get past the scrubber inlet during the short periods of highest flow would either remain in the flue immediately above the scrubber inlet elbow, or if lifted to the stack screen, would return to the scrubber inlet when the downflow of outside air occurred. Likewise most of the paper held on the scrubber inlet screen would fall back into the incinerator at the end of a burn when the scrubber was shut off.

Of the total particulate matter trapped by the scrubber water, 15% was ether extractible, largely fats. The ash content of the collected particulate matter was 54%.

With the same gas throughput the use of a single impinger tray would reduce the pressure differential across the fan from 7.6 to 4.9 in. water column and would reduce the motor size from $7\frac{1}{2}$ to 5 hp and the power consumption from 5.75 to 4.5 kw. Some reduction in collection efficiency could also be expected. Although most of the pollutant remained in suspension, and was carried to the drain by the overflow water, a deposit of sediment formed in the scrubber sump.

The effectiveness of the scrubber in reducing smoke has not as yet been determined. A white plume was present during cold weather when water vapor in the saturated scrubber exhaust condensed in the atmosphere. The plume re-evaporated within a short distance depending on atmospheric conditions. During mild weather no plume was observed.

It was found inadvisable to return the flue gases to the flue above the scrubber inlet and to eject them upward by an elbow. A circulation of scrubbed and raw flue gas was produced between the scrubber inlet and outlet which caused a continuous by-pass of some of the raw gas with resultant increase in emission to the atmosphere. If it should be necessary to vent the scrubber to the stack, it is suggested that an exhaust duct be installed inside the stack and extended through and beyond the stack screen.

Service-Door Locks

It is common practice for the refuse-charging hoppers or service doors to be installed without means for locking them. The tenants are thus free to charge refuse into the flue at all times, even including the combustion period. While unrestricted access to the incinerator flue is obviously a convenience to the tenant, and locks are an additional though minor expense to the building owner, charging during burning contributes to air pollution and other hazards. The reasons will become obvious from a consideration of the gas velocities in the flue.

Before a combustion period, while the incinerator and flue were at essentially building temperature (75–80°F), air flowed upward in the flue at centerline velocities below 3 fps in the region above the upper charging hopper, and at even lower velocities farther down in the flue. The outdoor temperature affected the flue draft and infiltration as in the case of any chimney in a building. However, during the periods of combustion, when the flue gases were hot, the velocities in the upper part of the flue increased to 10 fps, with peaks up to 22 fps. The tests also showed that flue-gas velocities up to 32 fps were possible when the furnace doors were opened during raking and during the first few minutes after light-off unless the incinerator room was under negative pressure.

In daily operation when the hoppers were not locked and the refuse was sometimes allowed to accumulate to the full height of the incinerator, or even into the base of the flue, paper napkins, sheets of newspaper, ladies hosiery, and other light refuse of high surface area were occasionally carried up the flue. Loose paper charged by a tenant during the first 20 minutes of a burn would be certain to be carried up to the screen. About once in eight weeks the stack screen became clogged by paper during the burn, and flue gas poured out of the leaks and vents of the service doors and into the building corridors,

beginning at the upper floor. Emergency relief was obtained by closing all air ports in the furnace and by opening a door on the stack screen or by rapping the screen.

The major difficulty with incinerator operation, according to the Fordham building superintendent, has been the clogging of the stack screen. The frequency of clogging had been reduced by asking the tenants not to discard newspapers into the flue. However, paper of all kinds is a major apartment refuse, and newspaper, even when used to wrap other refuse, can become unwrapped by impact and abrasion during the fall in the flue.

The experience with paper being carried up the flue had its counterpart in the carry-up sweepings and other fine particles that were not observed so readily as was paper. More of such particles were obviously carried up at high velocities than at low velocities. By the Stokes' and Newton equations, spherical or equivalent particles (density 1.0) of 740 microns or less are carried upward at velocities exceeding 10 fps, and 1800-micron particles are lifted by velocities of 20 fps.

To observe the interior of the flue, a glass window and an electric light were installed in the flue 10 ft above the upper residence floor. Shortly after light-off during the tests with locked hoppers, pieces of scorched paper from the furnace were seen floating in the gases and being carried upward against the stack screen, where they remained until the end of the burn. The open area of the screen was thus reduced temporarily by 10–20% in some cases, but not enough to affect the draft appreciably. The fluttering of the paper on the screen caused some of the brittle scorched paper to break, allowing particles to pass through the screen and into the neighborhood. Had the screen been in poor repair, as many are, more and larger pieces would have escaped. After the flue had again cooled and the gas velocities returned to lower values, the remaining pieces again fell into the flue and incinerator.

Based on the above experiences, it is recommended that hopper locks be used to reduce the emissions of particulate matter. Additional benefits would be increased safety by preventing the burning of fingers while charging hot hoppers on the lower floors and by preventing leakage of flue gas from the hoppers on the upper floors. As a further precaution, paper and light refuse should be raked away from the entrance of the flue to provide space at the top of the furnace before lighting the fire.

Figure 10 illustrates a form of locking mechanism in which a solenoid actuates a locking pin to engage the hopper. The solenoid is energized from a switch in the incinerator room. All of the hopper locks can be controlled simultaneously from the same switch. A light at the switch indicates when all hoppers are locked. A light at each hopper also notifies the tenant of a locked hopper.

To maintain the co-operation of the tenants it would, of course, be advisable to burn the refuse at regular posted times and to restore the hoppers to use without unnecessary delay after the charge has been burned and the residue has been removed.

Overall Evaluations

The primary objective of the program was accomplished by the demonstration and evaluation of several inventions and principles for reducing the emissions from existing single-chamber flue-fed incinerators. The findings are applicable to a wide variety of sizes and shapes of existing flue-fed incinerators. Some of the results will be useful in installations of the multiple-chamber incinerators. The devices are capable of operation by regular incinerator attendants who will follow simple instructions.

The major improvement has been made in reducing particulate matter and its soiling characteristics. Noxious gases have been reduced appreciably, as has smoke. Odor concentrations in the flue gas were evaluated but not fully. From the evidence available, no marked reduction of odor concentration was achieved.

Hopper Locks

Locks for the charging hoppers are necessary for the operation of the Hartmann and Werner incinerator devices. Although not vital to the use of the overfire jets, gas burner, and scrubber, the locking of hoppers during the periods of burning and furnace cleaning is nevertheless recommended for them also. The locks would help reduce emissions to the atmosphere, largely prevent the clogging of stack screens, and decrease exposure to possible burns from touching hot hoppers and to smoke-out from hoppers on the upper floors. Electric locks which can be operated from the incinerator room can be applied to existing hoppers at an installed cost of about $75 per hopper.

Gas Scrubber

The maximum reduction of particulate emission during the burning period was obtained by the use of a Peabody gas scrubber. Although the scrubber itself had a collection efficiency in the range of 88 to 96%, increasing with the dust loading of the gases, some allowance must be made for dust in the minor amount of flue gas that by-passes the scrubber inlet during periods of peak flow. However, an overall collection

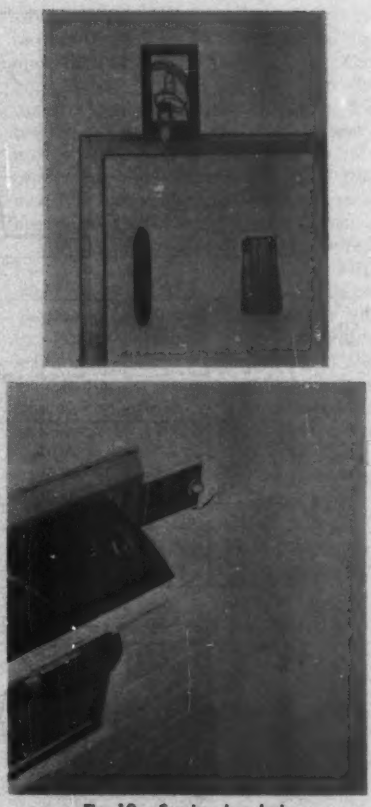


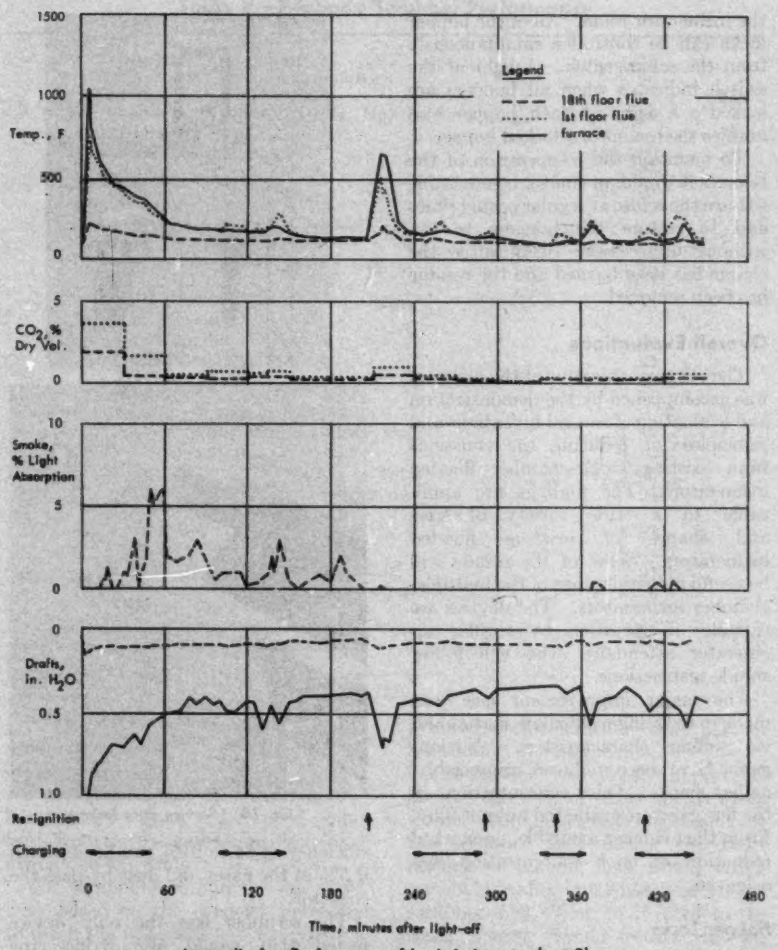
Fig. 10. Service door lock.

efficiency of 84 to 91% can be expected if 5% of the gases and dust by-pass the collector.

The scrubber was the only device tested that would also reduce the emission of the particulate matter that is carried up the flue between burning periods, such as when refuse is being charged or the furnace is being cleaned. (See Appendix C.) At the same time it would collect dust previously deposited on the flue and brushed off by falling refuse but re-entrained in the rising flue gases.

As measured by the von Brand recorder, the scrubber reduced the soiling property of the flue gas by 50%. Soiling is undoubtedly caused by the extremely fine carbonaceous particles which escaped combustion.

The scrubber collected 22% of the noxious gases. The effectiveness of the scrubber in removing odors was not determined. Although some odor was transferred to the scrubber water, the odor in the scrubber exhaust gases was in the same range of concentration as before. The effect of the scrubber in reducing smoke was not measured. No plume from the scrubbed gases was visible on mild days when the atmosphere was relatively dry. However, a light vapor plume may be expected from the scrubber exhaust during cold weather, which would largely mask light smoke. The vapor plume would be of



Appendix 1. Performance of basic incinerator (test 3).

no consequence above tall buildings, but there is the possibility of nuisance in the case of low buildings among taller buildings in congested areas.

Remote control of the scrubbers is practiced in a number of installations by locating a switch near the incinerator. The water supply is controlled by a solenoid valve. It is suggested that the scrubber could be started and stopped automatically under the control of temperature-sensing elements in the flue. Monthly cleaning of the scrubber sump and somewhat more frequent inspection of the inlet is recommended by the manufacturer.

Auxiliary Gas Firing

The use of a luminous gas flame over the incinerator charge and the simultaneous operation of overfire air jets decreased the burning time from 117 to 85 min, or 27%, and produced a residue of a lower content of combustibles. The burner heat release was 270,000 Btu per 100 lb of refuse charged. The burning time, and consequently the gas consumption, could have been reduced 15 to 20% if a 10% increase in residue weight had been considered satisfactory. The emission of particulate matter was reduced further than with any other combustion device tested, and was only 39% of that from the flue of the unmodified incinerator, while the noxious gas was reduced to only 29% and the smoke to 6% of the initial amounts.

The overfire air jets alone reduced the von Brand soiling index of the flue gas from 855 to 345, and gas firing reduced the index further to 100, which was the lowest value obtained from any combustion device. The radiation from the luminous flame undoubtedly accelerated the combustion of fine carbonaceous particles suspended in the gases and also maintained ignition in the devolatilized combustible on the hearth and grate.

Auxiliary fuel fired in the manner described undoubtedly increases the temperatures of the furnace roof, flue lining, and service hoppers above that ordinarily experienced. Exposed steel supports in the furnace roof would likely deteriorate somewhat more rapidly, which suggests the use of arched roofs, suspended blocks, or cast refractory roofs. A barometric damper to admit ambient air to the flue immediately above the furnace would reduce the gas temperatures in the flue and would regulate the draft simultaneously.

The hourly Btu rating of the gas burner installed in the Fordham incinerator was possibly a satisfactory compromise on the grounds of effectiveness, cost, temperatures in the flue, etc. Part of the heat was absorbed by the furnace walls and roof and the remainder heated the furnace gases. Smaller furnaces would require gas burners of lower Btu ratings, probably in the ratio of the plan areas of the furnaces. A suggested rule for sizing the gas burner, based on the ratio is as follows:

$$\text{Burner capy., Btu per hr} = \frac{22{,}000}{\text{(hearth + grate area in sq ft)}}$$

The investment cost of the installed gas burner and overfire air system would be less than that of the scrubber but the operating cost would be more, as detailed later in this section of the report. Because incinerator operators have other duties and may not shut off the gas burner promptly after the charge is burned, the use of an electric timer control is suggested. The timer could also shut off the overfire-air blower. The saving in gas would soon more than offset the cost of the timer.

Overfire Air Jets

The overfire-air blower with single manifold was the simplest and least expensive device tested, yet it reduced the particulate emission to 60% and the soiling index to 40%. Noxious gas and smoke were reduced somewhat but it is doubtful whether the odor of the gases was reduced. The jets reduced the time for burning the charge 20–25%, which undoubtedly resulted in higher furnace temperatures observed. However, an average furnace temperature of 630°F is not impressive as an aid to combustion, even though it was higher than the 488°F average without jets. Additional furnace temperature is required, which was the reason for adding a gas burner.

The design features were simple and the device could be fabricated in any metal shop. All that is required is a single, drilled, pipe manifold which is closed at one end and attached directly at the other end to a blower mounted on the furnace front. The flow of air keeps the manifold cool enough to prevent deterioration of the metal. The air velocity in the 18 nozzles was 3000 fpm for this application. From the beginning of the burn to the end the distance between the nozzles and the top of the burning refuse changed from almost 0 to 5 ft, which means that the jets had undoubtedly impinged on the

charge much of the time while creating turbulence in the furnace gases. The velocity in the first portion of the 5.13-in. ID manifold was 1000 fpm, although velocities of 2000 fpm would have been satisfactory, as would have been the case had a manifold of 3.6 in. ID been used.

A variety of jet arrangements are possible, even with a single manifold, depending on furnace configuration. In the location used in the tests reported, the jets mixed with most of the furnace gases during the entire burn. The same general arrangement can be used in a variety of sizes and shapes of flue-fed incinerators. The nozzle diameters and/or number can be reduced for smaller furnaces, with air delivery proportional to average burning rate. More experience on applications to small incinerators is needed to establish design data. The use of drill holes instead of short tubes reduces the penetration of the jets and avoids impingement on the charge after a layer of ash has formed.

Hartmann Device

The invention reduced the emissions of particulate matter to 55%, reduced the soiling property of the flue gas to 28%, and eliminated the smoke nuisance. The noxious gases were reduced to 71% of that from the basic incinerator.

The elimination of smoke and the reduction of floating paper and other particulate matter would satisfy most of the common complaints against the unmodified incinerator. The secondary combustion chamber with inlet grille was a positive means for preventing the flight of sizable pieces of scorched paper up the flue to the stack screen. The reduction of odor in the flue gas was undoubtedly due to dilution by barometric air.

Additional tests would be necessary to determine whether a tubular secondary combustion chamber with auxiliary gas firing has net advantages over direct auxiliary firing of the primary combustion chamber. More definite and intimate mixing of the gases should be possible in the smaller tubular chamber than in the larger primary chamber. The effectiveness in burning smoke in the secondary chamber was demonstrated, even under conditions that produced unburned gases.

The Hartmann device reduced the furnace capacity more than any other device tested and lengthened the burning period per 100 lb of charge.

Higher rates of primary combustion than were obtained will be necessary to reduce the charge in the time deemed acceptable. Further progress can undoubtedly be made in that regard. The loss of furnace height and volume by a barometric air duct and a secondary chamber inside the primary chamber is serious, except where the flue-fed incinerators have ample volume to hold the overnight accumulation of refuse.

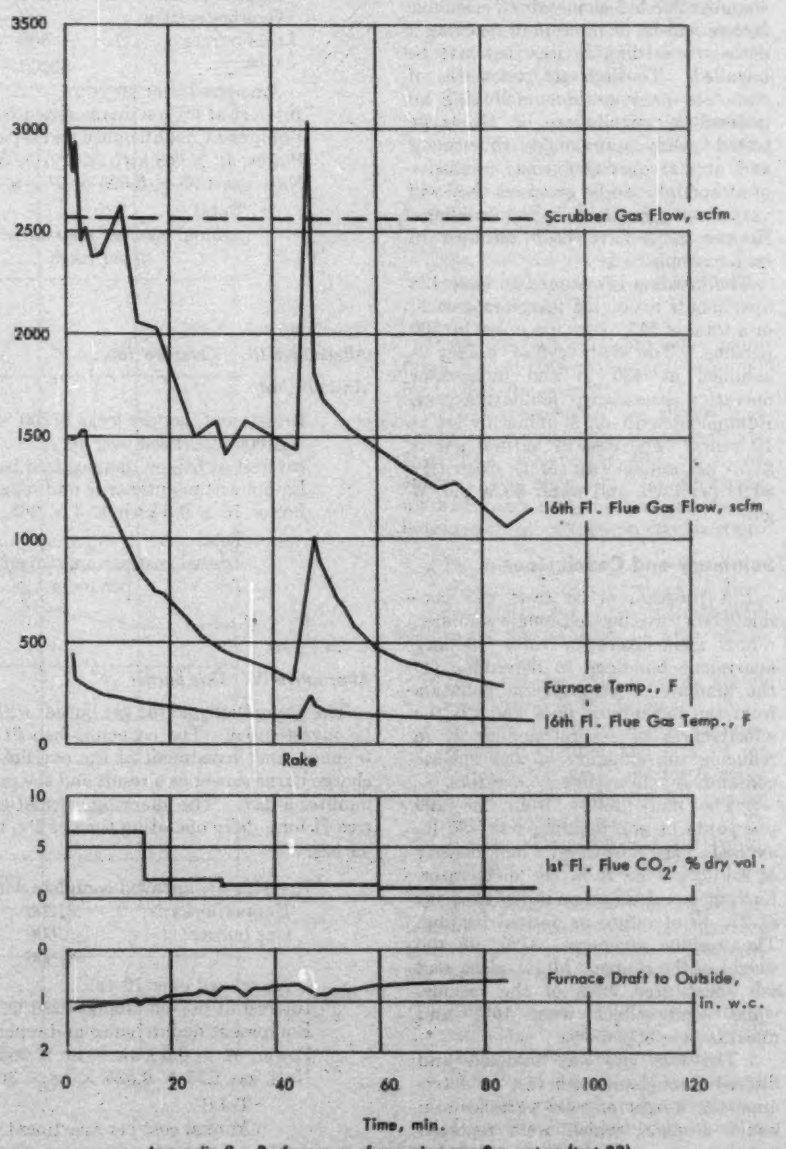
The life expectancy of the flame tube and the possible buildup of ash deposits in the flame tube could not be determined until the unit had been operated for a longer period of time. Additional tests are suggested in which the gas burner heat release would be increased to 350,000 Btu per hr and the rate of primary combustion increased. The net result should be a shortening of the combustion period, and a reduction in noxious effluent.

Werner Device

The rapid combustion of the refuse and the retention of floating paper by a screen in the base of the flue were two advantages of the Werner principle of incineration. When the device is operated skillfully and rapidly the hoppers need not be locked over 30 minutes from light-off to removal of the residue. The emissions of dust, odor, noxious gas, and smoke were no improvement on those from the unmodified incinerator, although the soiling index of the flue gas was 64% less.

More labor and attention was required to operate the incinerator than with other devices tested. More weight and volume of residue was removed per 100 lb of refuse charged. The incinerator attendant would be tempted to let the fire burn out more completely to reduce the amount of residue, in which case the emissions to the flue gas would be increased.

The Werner device would un-



Appendix 2. Performance of one-pipe overfire system (test 33).

doubtedly reduce the number of complaints against the unmodified incinerator by (1) preventing the emission of paper from the incinerator, and (2) shortening the period of emission, thus eliminating the long smoldering fire that emits odors most of the day.

A slower rate of burning by reducing the supply of undergrate air would undoubtedly reduce the quantity of fly ash lifted off the burning charge, but would increase the time required of the attendant. Overfire air jets may also be helpful in reducing the emissions. Auxiliary gas firing at a sufficient rate to be effective would probably overheat the screen.

Investment and Operating Costs

Because there are several methods for reducing the emissions from single-chamber flue-fed incinerators, economic factors will be of interest in reaching a decision regarding devices that may be installed. To illustrate, estimates of costs are presented for modifying an incinerator installation of the type tested. Only approximate investment and annual operating costs, exclusive of attendant, can be given, as they will vary among contractors and buildings. Hopper locks have been included in each example.

The building is assumed to have 128 apartments averaging four rooms each, or a total of 512 rooms, occupied by 300 persons. The daily refuse weight is assumed at 430 lb and incinerator operation is necessary 365 days a year. Equipment write-off is uniformly set at 10 years. The cost of natural gas is $1.75 per million Btu (Mcf), electricity $0.04 per kwh, and water $0.50 per M gal.

Summary and Conclusions

1 A program of 38 tests was conducted on three flue-fed, single-chamber, refuse incinerators in three 16-story apartment buildings to determine (1) the amount of atmospheric pollution from the incinerator flues and (2) the effectiveness of several appliances in reducing the emission of atmospheric contaminants from such incinerators.

2 The daily refuse from the 299 occupants of one building was 430 lb, average. The refuse had a bulk density of 4.1 lb per cu ft in the incinerator. Each incinerator had an initial capacity of 275 lb of refuse in normal loading. The residue averaged 37% of the weight of the charge. Metal, glass, and ash constituted 76% of the residue, while combustibles were 16% and moisture was 8%.

3 The flue gas was sampled and filtered throughout each test to determine the weight of solid particles and liquid droplets, which were reported together as particulate matter. In-

Alternative I. Flue-Gas Scrubber with Two Impingement Trays

Annual Cost

Investment, scrubber installed complete with stack, wiring, piping, $4000 16 Hopper locks at $75 ea. installed, $1200 10-yr. amortization of $5200	$ 520
Interest at 6% on unamortized balance	156
Equipment maintenance and repair	100
Power, 4¢ × 6 kwh × 3 hr × 365 days	263
Water, 60 × 3 × 365 = 65,700 gal at $0.50 per M gal	33
Total	$1072
Annual cost per apartment	$8.38
per room	$2.09

Alternative II. Overfire Jets and Gas Burner

Annual Cost

Investment, installed complete with wiring and piping		
Hopper locks	$1200	
Overfire system	400	
Gas burner	600	
	$2200	
Amortized over 10 years		$220
Interest at 6% on unamortized balance		66
Equipment maintenance and repair		50
Power, 4¢ × 0.8 kwh × $2^1/_4$ × 365		26
Natl. gas 1.75 × 0.525 × $2^1/_4$ × 365		755
Total		$1117
Annual cost per apartment		$8.73
per room		$2.18

Alternative III. Overfire Jets

Annual Cost

Investment, hopper locks $1200, and jet system $400 $1600 amortized over 10 yr	$160
Interest at 6% on unamortized balance	48
Equipment maintenance and repair	20
Power 4¢ × 0.5 kwh × 3 × 365	22
Total	$250
Annual cost per apartment	$1.95
per room	$0.49

Alternative IV. Gas Burner

The performance of the gas burner without the benefit of overfire-air jets is still to be investigated. The economic benefit from the saving in electric power, maintenance, and investment of the overfire jet system can easily be wiped out if the charge burns slower as a result and the gas burner must operate longer by 16 or more minutes a day. The following calculations may be compared with those in Alternative II for a daily operating time of $2^1/_4$ hours when overfire jets supplement the gas burner.

		Daily Operating Time, hr	
Investment, installed complete with wiring and piping			
Hopper locks	$1200		
Gas burner	600		
	$1800	$2^1/_4$	$2^1/_2$
Amortized over 10 yr		$180	$180
Interest at 6% on unamortized balance		54	54
Equipment maintenance and repair		30	30
Power, 4¢ × 0.3 kwh × hr × 365		12	11
Natl. gas 1.75 × 0.525 × hr × 365		923	840
Total		$1199	$1115
Annual cost per apartment		$9.37	$8.71
per room		$2.34	$2.18

Alternative V. Hartmann Device

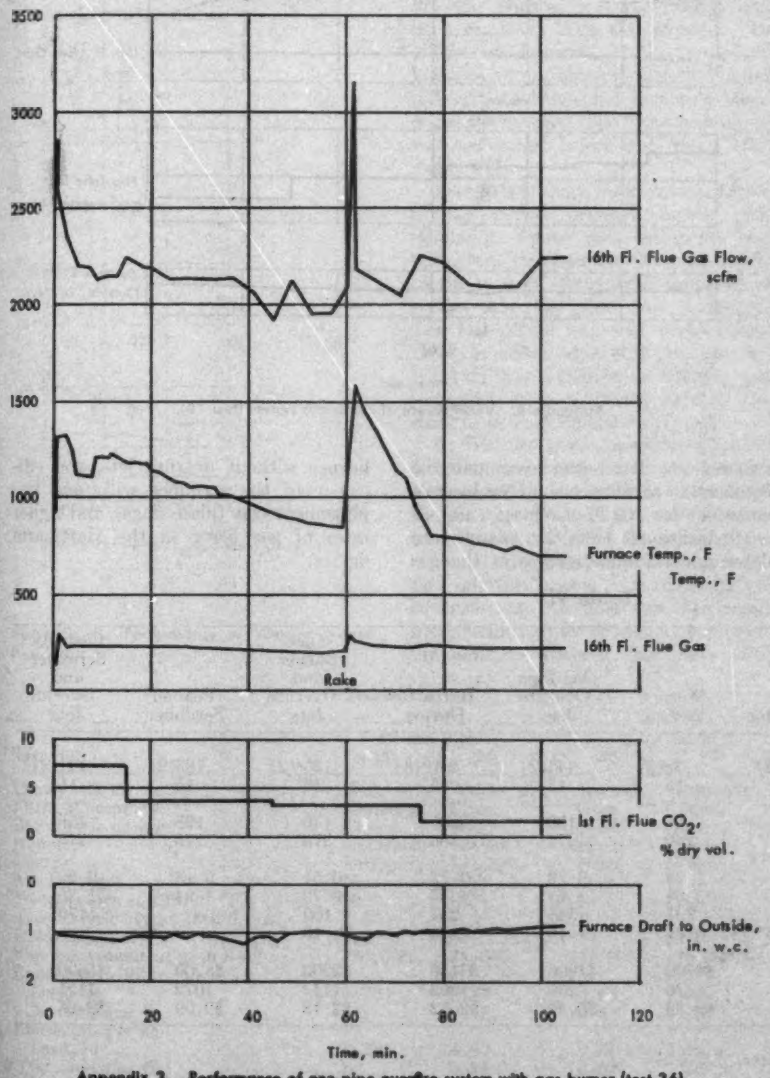
Annual Cost

Investment, Hartmann device $1950, hopper locks $1200 installed with wiring, piping	
$3150 amortized over 10 years	$315
Interest at 6% on unamortized balance	95
Equipment maintenance and repair	150
Power 4¢ × 0.5 × 4 × 365	29
Natl. gas 1.75 × .275 × 4 × 365	703
Total	$1292
Annual cost per apartment	$10.10
per room	$ 2.52

Alternative VI. Werner Device

Annual Cost

Investment, Werner device $1500, hopper locks $1200 installed	
$2700 amortized over 10 yr	$270
Interest at 6% on unamortized balance	81
Equipment maintenance and repair	75
Water	negl.
Total	$ 426
Annual cost per apartment	$3.32
per room	$0.83



Appendix 3. Performance of one-pipe overfire system with gas burner (test 36).

completely burned gases in the flue were determined and were reported as noxious gases. The area-covering blackness of the particulate matter was measured by the von Brand apparatus and reported as Q-Ruds. The optical density of the smoke in the flue was measured by a photoelectric meter. The concentration of odor in the flue gas was determined by the ASTM perception-threshold method. Major reductions in all emissions except odor were demonstrated.

4 The appliances tested are listed below:

- *a* Overfire air jets to aid combustion by providing turbulence in the furnace.
- *b* A luminous-flame gas burner operated with overfire air jets in the incinerator chamber.
- *c* The Werner principle for rapid combustion, with all gases passing through a nichrome wire screen at the entrance to the flue.
- *d* The Hartmann device which includes a gas-fired stainless-steel secondary-combustion chamber in the incinerator furnace.
- *e* The Peabody gas scrubber for cleaning the flue gas with water.
- *f* Locking of the service hoppers in the flue was practiced on the tests to simulate the effect of automatic hopper locks.

These appliances require no more furnace draft than is ordinarily required for incinerator operation.

5 The investigation has shown that emissions of atmospheric contaminants from the incinerator flues can be reduced by each of the following methods, and that the best results are obtained by all of them in combination:

- *a* By hopper locks to prevent the charging of loose particles of dust, paper, lint, etc., while the velocities in the flue are high, as when refuse is burning.
- *b* By appliances that promote better combustion in the furnace.
- *c* By care taken by the incinerator operator to limit the flow of air through the grate during burning and through and over the residue during its removal.
- *d* By scrubbing the flue gas before discharge to the atmosphere.

6 To evaluate the several devices for possible application to an existing incinerator, it is advisable to consider the following factors, among others:

- *a* Effectiveness of the devices in reducing emissions, especially particulate matter and smoke.
- *b* Benefits to tenants and community.
- *c* Requirements of local ordinances.
- *d* Furnace volume available for refuse charge and appliance.

e Effect on schedule of daily incinerator operation.
f Time hoppers must be or should be locked.
g Space for gas scrubber.
h Investment and operating cost, combined as annual cost.

7 The performance and cost of the incinerator modifications will vary for each individual installation. Table VI is indicative for a 16-story building housing 300 persons in 128 apartments, averaging 4 rooms each. Automatic hopper locks costing $1200 have been included with each appliance, because they are necessary with the Hartmann and Werner devices and are advisible with the others.

8 The one-pipe overfire jet system is the lowest cost device tested that produces a substantial reduction in particulate matter, smoke, Q-Ruds (soiling) and time of operation.

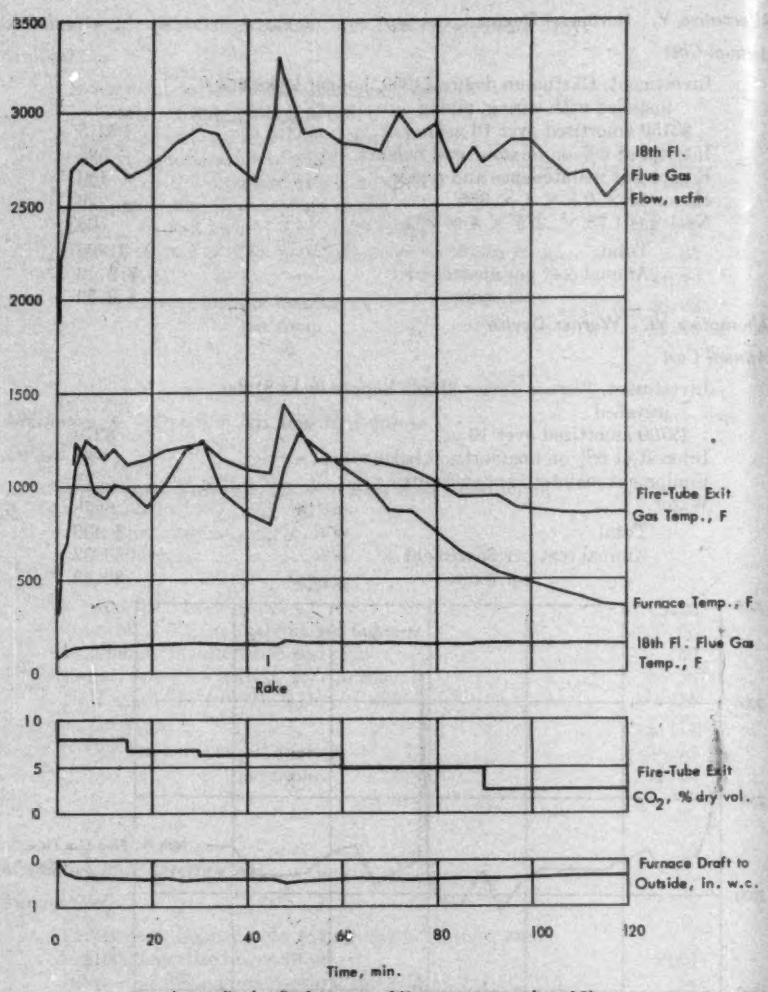
The lowest emission of particulate matter will result from the use of the flue-gas scrubber, even when auxiliary gas firing is not used. Auxiliary gas firing reduces the amount of particulate matter, noxious gas, smoke, Q-Ruds, and time of operation. The annual cost of a scrubber is substantially equal to that of auxiliary gas firing and overfire jets.

9 The emissions of particulate matter in lb per 1000 lb of flue gas corrected to 12% CO_2 have been included below as a matter of interest only.

Basic incinerator	3.81 lb
One-pipe overfire jets	3.65
Two-pipe overfire jets	3.55
Gas burner and jets	1.35
Hartmann device	1.48
Werner device	4.39

A direct comparison of these values is misleading because of the large difference in total gas flow, time of operation, and the fact that natural gas was burned in addition to refuse with two devices. It is better to compare the combustion performance on the basis of emissions per 100 lb of refuse.

10 Additional tests are planned to determine the effectiveness of the gas burner without overfire jets, the efficiency of the scrubber with one impingement tray (plate stage), and higher rates of gas firing in the Hartmann device.



Appendix 4. Performance of Hartmann system (test 18).

Table VI

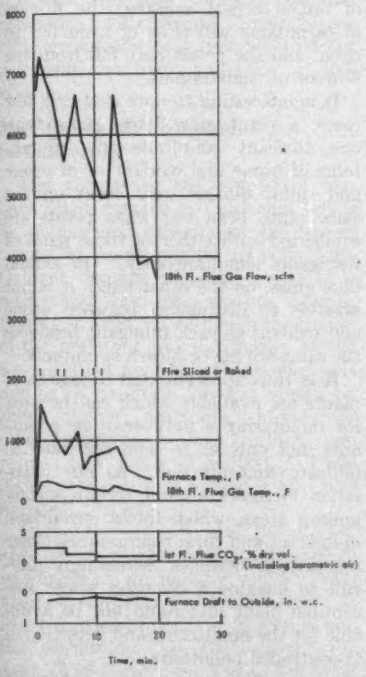
	Basic Incinerator	Werner Device	One-Pipe Overfire Jets	Hartmann Device	Gas Burner and Overfire Jets	Peabody Scrubber	Peabody Scrubber and Overfire Jets
Daily Operation, min.							
Burning only (no. of burns)	183(2)	38(2)	141(2)	240[a](3)	125[a](2)	183(2)	141(2)
Residue removal	15	15	15	15	15	15	15
Total min., hoppers locked	198	53	156	255	140	198	156
Furnace capacity, lb	275	240	275	200	275	275	275
Emissions, lb per 100 lb of charge							
Particulates	1.31	1.29	0.79	0.72	0.51	0.13[b]	0.09[b]
Noxious gases	2.48	3.01	1.61	1.75	0.73	1.94[c]	1.26[c]
Q-Ruds	855	307	345	237	100	—	170
Smoke	2.81	0.71	1.10	0	0.18	—	—
Cost							
Investment	$1200	$2700	$1600	$3150	$2200	$5200	$5600
Annu l, total	166	426	250	1292	1117	1072	1151
Annual, per room	$0.30	$0.83	$0.49	$2.52	$2.18	$2.09	$2.25

[a] Adjusted for equal burn-out of residue.
[b] Based on 90% collection of particulate matter.
[c] Based on 22% removal of noxious gases.

Appendix A. Weight of Noxious Gases in Flue

	Basic Incinerator	Two-Pipe Overfire Jets	One-Pipe Overfire Jets	Gas Burner and Overfire Jets 18th Fl.	Gas Burner and Overfire Jets 1st Fl.	Hartmann Device 18th Fl.	Hartmann Device 1st Fl.	Werner Device
Noxious gases								
aldehydes, as formaldehyde	0.64	0.34	0.29	0.17	nd[b]	0.35	nd	0.09
Ammonia	0.05	0.07	0.03	0.07	nd	0.03	nd	0.03
Esters	2.96	1.97	1.79	2.99	0.50	2.22	0.48	2.38
Nitrogen oxides, as NO_2	0.01	0.03	0.01	0.02	nd	0.05	nd	0.05
Organic acids, as acetic	3.09	1.44	2.28	7.03	1.41	5.69	2.84	4.65
Phenols, as phenol	0.01	0.01	0.02	0.02	nd	0.01	nd	0.01
Sulfur dioxide	0.07	0.03	0.01	0.01	nd	0.01	nd	0.01
Total per test, lb avg	6.83	3.89	4.43	10.31	1.9[a]	8.36	3.32[a]	7.22
Lb per 100 lb refuse	2.48	1.41	1.61	3.75	0.69[a]	4.19	1.66[a]	3.01
Flue gas, Mscf for test	218	191	154	213		313		113
CO_2, avg %, dry vol	0.70	0.71	0.62	0.78		0.50		1.08
Test no.	1, 2, 6	11, 12	33, 34	36, 38 (37)		16, 18, 21		22, 23, 29

[a] For comparison, increase by 5% to include other noxious gases.
[b] nd = not determined.



Appendix 5. Performance of Werner system (test 22).

Appendix B. Flue Emissions Between Burns

Dust and odor in the air flowing up the flue were detected even when no fire was burning and the residue had been removed from the furnace. To obtain an estimate of flue emissions between burns, four tests were run under different conditions not involving burning of the charge. The furnace chamber was vacuumed before each test. (See Table VII)

Test 20 is perhaps most representative of the period between burns. Air admission from the basement was restricted, the hoppers were accessible to the tenants for random dropping of refuse, and the flue was unheated. The test period was over three hours. Dust emission was 0.38 lb per hr. Noxious gas emission, although not measured, was probably about the same as in Test 26 or 0.34 lb per hr.

In Test 26, the hoppers were locked but the furnace and barometric dampers were opened. In addition, a louver on the air duct connecting the incinerator room to the outside of the building was removed during test to provide more air flow into the furnace. An accumulation of dust from this duct was discharged into the incinerator room and some of it undoubtedly entered the flue. The high dust rate of 1.42 lb/hr may reflect the presence of this dust during the short test period of 0.5 hr.

Tests 28 and 17 show the effect of higher velocities in removing particulates from the flue walls. The dust rate increased with velocity for Tests 20, 18, and 17 is roughly 0.2 lb per hr per fps. This figure probably falls off with time but is renewed after each burn.

Test 28 shows the effect of temperature of the flue gas of distilling noxious gases from the flue walls. A temperature increase from 80° to 94° at the 19th fl. almost doubled the noxious gas. However, Test 17 is not comparable since the temperature increase to 130° is caused by burning of auxiliary gas fuel which may in itself be a source of noxious gases.

It was outside the scope of the program to investigate these phenomena further. Without data taken over a 24-hour period, one can only speculate on the magnitude of the daily emission that occur during periods of no fires or residue removal. However, it is evident that such emissions are significant.

Table VII

Test no.	Before Burn 20	Before Burn 26	After Burn 28	After Burn 17
Incinerator device	Hartmann	Werner	Werner	Hartmann
Furnace dampers	Closed	Open	Open	Closed
Barometric damper	Closed	Open	Open	Open
Hoppers	Unlocked	Locked	Locked	Locked
Charge	Dropping	Loaded	None	None
Auxiliary gas	No	No	No	Yes
Temperature at 19th fl, °F	70	80	94	130
Average velocity at 18th fl, fps	2.8	2.4	3.7	6.2
Duration, min.	191	30	34	60
Flue gas volume at 18th fl scf	180,000	24,500	41,600	120,000
Emissions, total for test				
Dust, lb	1.22	0.71	0.46	1.15
Noxious gas, lb	nd	0.17	0.34	4.36
Emissions, per hr				
Dust, lb	0.38	1.42	0.81	1.15
Noxious gas, lb	nd	0.34	0.60	4.36

Acknowledgment

Numerous organizations and individuals participated in the program. The authors wish to express their sincere appreciation to each of them.

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(*Continued on page 207*)

USE of PLANTS for Air Pollution MONITORING*

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Air pollution is an age-old problem and during the past century its injurious effects on vegetation have become well recognized. Many of the constituents of polluted atmospheres, particulates, and gases, have deleterious effects on plants and of these, gases such as fluorine, oxidants, ethylene, and sulfur dioxide, are the most important. Reviews of effects and symptoms on plants of these and other pollutants are given by Adams,[1] Middleton, Darley, and Brewer,[16] Thomas,[21] and Zimmerman.[23]

Because the materials involved differ so greatly in their chemical composition and activity, it is reasonable to expect that their effects on a variety of plants will also differ. This, in fact, is the case, and for this reason, plants offer an excellent monitoring tool to detect the presence of air pollution, and often give the very first evidence that the air is polluted. The present paper discusses the utility and present usefulness of plants in the role of monitoring for air pollution.

Plants as Indicators

Certain basic considerations are common to all situations where plants are used to monitor air pollutants. The plants, either those occurring naturally or those that are cultivated, must be susceptible and display symptoms or markings characteristic of the pollutant or pollutants in question; they should be growing in suitable environment and should have rather wide distribution; the observer must not confuse symptoms of plant diseases and injury from insect pests, frost, or heat with those of air pollutants.

Using naturally occurring vegetation may have some limitations because of the absence of susceptible varieties or poor growing conditions. Where this difficulty exists, it can be overcome by planting susceptible species in good sites or by growing these species under controlled conditions that give maximum sensitivity and then placing them for stated intervals in special exposure chambers in the area to be monitored.[7, 13, 18]

Fortunately, for the purposes of monitoring, but perhaps unfortunately for the farmer, home owner, or commercial ornamental grower, a given toxic pollutant usually affects a rather broad spectrum of plants including native species and, more importantly, the cultivated crops, both rural and urban among the field, vegetable, and ornamental plant species. A number of workers, by correlating field observations with controlled fumigations, have described the type and extent of injury on a number of plants from a variety of pollutants at given concentrations. Thus, Benedict and Breen[2] selected ten widely distributed weeds and described their relative susceptibility as indicators for ammonia, chlorine, hydrogen fluoride, hydrogen sulfide, oxides of nitrogen, and sulfur dioxide. Thomas[21] refers to the susceptibility of 350 species to sulfur dioxide, and Cole[5] describes the usefulness of ten native indicator plants for monitoring for sulfur dioxide in the Tennessee Valley. Others describe symptoms of acid aerosols, hydrogen fluoride, and oxidants on a variety of plants;[12, 14, 15] of hydrogen fluoride on prune, gladiolus, and pine[17]; of ozone on tobacco[11] and grape[19]; and of ethylene on orchids[8] and other plants.[6] Most of these toxicants are injurious at concentrations of one part per million or less, and some at concentrations as low as a few parts per billion.

For the more important gaseous pollutants, the most characteristic symptoms may be described briefly as follows: Oxidants—a silver, bronze, or otherwise metallic sheen on the under leaf surface of affected plants. Ozone—a stippling, mottling, or bleaching of the upper leaf surface. Color of the stipple marking may vary from light tan or ivory to reddish or almost black. Fluorides—lesions are usually confined to the leaf margins of broad-leaved species and are generally tan or dark brown in color. Affected tissues may become brittle and fall from the unaffected portion of the leaf. The tips of pine and fir needles become yellow or dark brown. Sulfur dioxide—acute injury occurs between the veins and affected tissue is bleached to a light tan or may become brown. The veins characteristically remain green. Injury on pine and fir needles is identical to that caused by fluorides. Ethylene—epinasty, or growth curvature of leaf petioles, is characteristic of ethylene injury. The tissue between the veins of orchid sepals collapse, the flowers of carnations will close or even fail to open, and the petals may fall from the flowers of snapdragons.

It is interesting to note that in a few cases, a plant may detect more than one toxicant simultaneously. Symptoms of ozone and oxidant or of ozone and sulfur dioxide may occur on the same pinto bean leaf when plants are fumigated with either of these pairs of fumigants simultaneously. On annual blue grass, on the other hand, it is not possible to distinguish between ozone and oxidant as each fumigant produces the same stipple or bleach symptoms.

It is thus apparent that a variety of plants are available which can be used for monitoring a number of air pollutants, not only as to kind but also to indicate concentration. As our population increases around certain metropolitan areas, which forces our urban, industrial, and rural communities closer together, it becomes increasingly difficult to imagine a situation where susceptible plant life would not be available for the monitoring and detection of uncontrolled pollutants.

Nature of the Pollutants

Brief consideration should be given to the nature and sources of the pollutants involved. Many of those known to cause plant damage today have been identified and related to rather specific sources. In the course of developing this information, chemical and physical methods have emerged for monitoring such pollutants as sulfur dioxide and fluorides, and more recently, for hydrocarbons such as ethylene.[9, 20] While not related to a specific site, measurements can also be made for ozone.[3, 22] When such methods are available they can be used in conjunction with plants. Most methods, however, are relatively expensive, and observations on plants

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may still be the least expensive and the more important, particularly in areas where pollution of the air is not suspected and chemical monitoring would not normally be in effect.

No chemical or physical method is known for measuring the phytotoxic components of the oxidant-type pollutants. These, like ozone, are not traceable to specific sites but are the product of photochemical reactions involving oxides of nitrogen and organic materials, particularly hydrocarbons. Solutions of potassium iodide or phenolphthalin measure the oxidizing ability of the polluted air. Studies in California[13] suggest that severity of damage is not always correlated with oxidant level but that the percentage of plants damaged and frequency of damage is correlated with oxidant level. These reagents do not measure the phytotoxicants but may measure oxidants associated with them. Thus, plants still remain the only reliable tool for detecting the toxic materials in this system.

Monitoring for Pollutants in California

The occurrence and spread of oxidant plant damage in California serves as an excellent example of the use of plants for monitoring for air pollutants. Oxidant damage was first found in a rather restricted area in Los Angeles County in 1944.[13] Although the nature of the pollutant was not known at the time, it was known that the damage was due to air pollution but not caused by sulfur dioxide, ammonia, chlorine, or other pollutants whose symptoms on plants had been described. Thus, plants were the first indicator of a new pollution problem.

During the next six years, the affected area became larger and plant damage was found throughout the south coastal plain of southern California, south to San Diego and inland to Riverside and San Bernardino. In the interval, the research of Haagen-Smit et al.[10] showed that damage indistinguishable from that occurring naturally was due to the reaction products of ozone and certain unsaturated hydrocarbons.

By 1950, typical oxidant injury was being reported in the San Francisco Bay area. Middleton and Paulus[15] report in some detail the results of a statewide plant damage survey in 1955. The kind, extent, and location of injury to 40 selected plant species from among field, vegetable, fruit, and flower crops and eight weeds were indicated on mark-sense IBM cards by trained farm advisors in each county. Out of almost 2700 reports, 544 indicated positive damage from six counties of southern California and from five counties in the Bay Area. The principal toxicants in order of importance were oxidants, ethylene, and fluorides. Occasional reports of sulfur dioxide were made and related to specific local sources.

The survey has continued, and up to the present, oxidant damage has been reported additionally in seven counties in the Central Valley. During 1958 relatively high oxidant levels were reported in Central Valley communities by the State Department of Public Health.[4] Plant damage in the Valley is not severe; its occurrence, however, prior to any other measurements, again points up the importance and utility of plants in monitoring for air pollutants.

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A.F. of A. Offers Help To Hayfever Sufferers

Several million Americans stock up each spring and summer with nasal tissues, inhalers, nose drops, and antihistaminics in anticipation of the hay fever season. Some have already experienced attacks of sneezing, nasal discharge, and weeping eyes. Others have not yet begun to suffer seriously because, in a large part of the country, the peak of the season is during late summer, mid-August to mid-September, when ragweed pollen fills the air.

As a public service, the Allergy Foundation of America offers to sufferers from seasonal hay fever an informative 16-page handbook, "Hay Fever and What You Can Do About It" which can be obtained from the Foundation's office, 801 Second Avenue, New York 17, New York, for 25¢.

Hay fever affects some people in every part of the country. The majority suffer from seasonal hay fever, which is caused mainly by the wind-blown pollen grains of various weeds, grasses, and trees. Ragweed is public enemy number one east of the Rocky Mountains.

Elimination of ragweed is an important public health problem and the subject of much attention by air-pollution experts. Since pollens may be air-borne for many miles, purely local control measures are not entirely effective.

CORRELATION of DUST SCRUBBER Efficiency*

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Although scrubbers have been in industrial use for collection of dusts and mists for over 100 years, their operation is still not well understood. The basic mechanisms of particle deposition[19] are known qualitatively, but their quantitative relationship to measurable performance variables remains largely unexplored. There is no design theory for scrubbers comparable to those which have been developed for fibrous filters or electrostatic precipitators, despite some efforts in this direction.[11]

There is, however, a useful empirical method for correlating scrubber efficiency as a function of the power dissipated per unit of gas flow rate. A number of writers have observed that the efficiencies of a number of types of scrubbers are functions of the power consumption.[1, 2, 7, 8, 9, 12, 16, 21, 27] It is now common practice to correlate the efficiency of venturi scrubbers as a function of the pressure drop across the venturi.[1, 2, 7, 8, 27]

Lapple and Kamack[17] investigated several typical contacting devices in which power consumption takes the form of gas pressure drop, and found that all gave substantially the same efficiency on a given aerosol for the same pressure drop. They concluded that the dominant factor in efficiency was probably related to turbulence in contacting. They suggested that the dissipation of energy from other sources, such as liquid sprays or a rotating member, might be equivalent to that from gas pressure drop. Semrau, Marynowski, Lunde, and Lapple[22] applied this method to correlation of efficiency data for pilot plant venturi, pipeline, and cyclonic spray scrubbers operated on lime kiln and Kraft recovery furnace dust and fume. They successfully correlated their own data and additional data from the literature, and found that power dissipated in hydraulic spray nozzles was in fact equivalent to that dissipated in gas pressure drop.

In this paper, this method of correlation is applied to literature data for a variety of aerosols and scrubbing equipment.

Method of Efficiency Data Presentation

The conventional basis for expressing the effectiveness of particulate collection is efficiency, η. However, the efficiency is usually an exponential function of the process variables for most types of collectors, and hence is, for correlation purposes, an insensitive function in the high efficiency range.[22] The penetration, $1 - \eta$, is generally preferable under these conditions. Still better is the number of transfer units, N_t, here defined by:

$$N_t = \ln\left(\frac{1}{1-\eta}\right) \qquad (1)$$

or

$$\eta = 1 - e^{-N_t} \qquad (2)$$

Table I shows the numerical relationship of efficiency to number of transfer units for some salient values of N_t.

Contacting Power

In scrubbing, the process of contacting the gas with liquid results in dissipation of mechanical energy in fluid turbulence (in gas and liquid phases) and, ultimately, as heat. The corresponding power dissipated, expressed as power per unit of volumetric gas flow rate, is here termed the "contacting power." The contacting power can be derived from: (*a*) the kinetic energy or pressure head of the gas stream; (*b*) the kinetic energy or pressure head of the liquid stream; or (*c*) energy supplied mechanically by a rotor.

The total power derived from the liquid or gas stream is given by the product of the volumetric flow rate and the change in pressure (assuming incompressible flow). Division of these total power terms by the gas flow rate gives the contacting power. The effective change in pressure comprises only that portion of the total pressure change which represents energy dissipated in scrubbing, and not that which results only from velocity changes or from friction losses in parts of the equipment which may be operating dry.

The contacting power derived from the gas stream is given approximately by the simplified dimensional equation

$$P_G = 0.157\,F_s \qquad (3)$$

Across actual scrubbers, changes in the kinetic energy of the gas stream are usually small, and the friction loss, F_s, is essentially equal to the pressure drop, Δp.

The power derived from the liquid stream (as, for instance, in a hydraulic nozzle) may be calculated from

$$P_L = 0.583 p_F \left(\frac{q_L}{q_G}\right) \qquad (4)$$

This equation assumes that the residual kinetic energy of the liquid stream is negligible after contacting. If all this power is dissipated, then P_L is equal to the contacting power. In some instances, as for instance in ejector-type scrubbers, a portion of the power input may serve to increase the pressure or the kinetic energy of the gas stream. In such a case, the corresponding amount of power must be subtracted from that given by Equation 4, to give the contacting power.

In the case of pneumatic spray nozzles, the combined power of the compressed air and liquid streams should be

Table I—Relation of Efficiency to Number of Transfer Units

Number of Transfer Units,* N_t	Collection Efficiency, %
0.10	9.52
0.50	39.35
1.0	63.21
2.0	86.47
3.0	95.02
4.0	98.17
5.0	99.33
6.0	99.752
7.0	99.909
8.0	99.967
10.0	99.9955

* Based on relation: $N_t = \ln\left(\frac{1}{1-\eta}\right)$, where η = fractional efficiency.

* Presented at the 52nd Annual Meeting of APCA, Hotel Statler, June 21–26, 1959, Los Angeles, Calif.

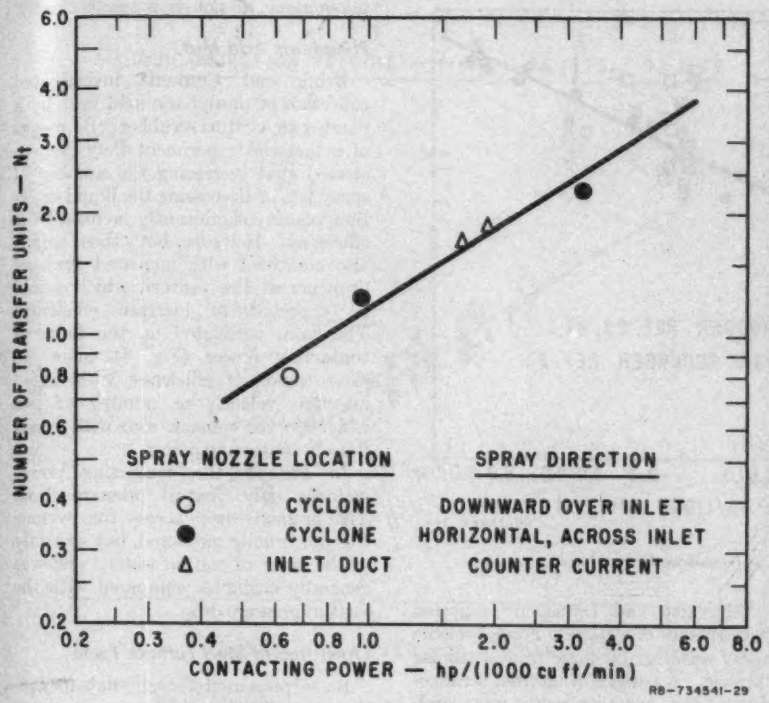

Fig. 1. Performance of cyclone scrubber on talc dust.[10]

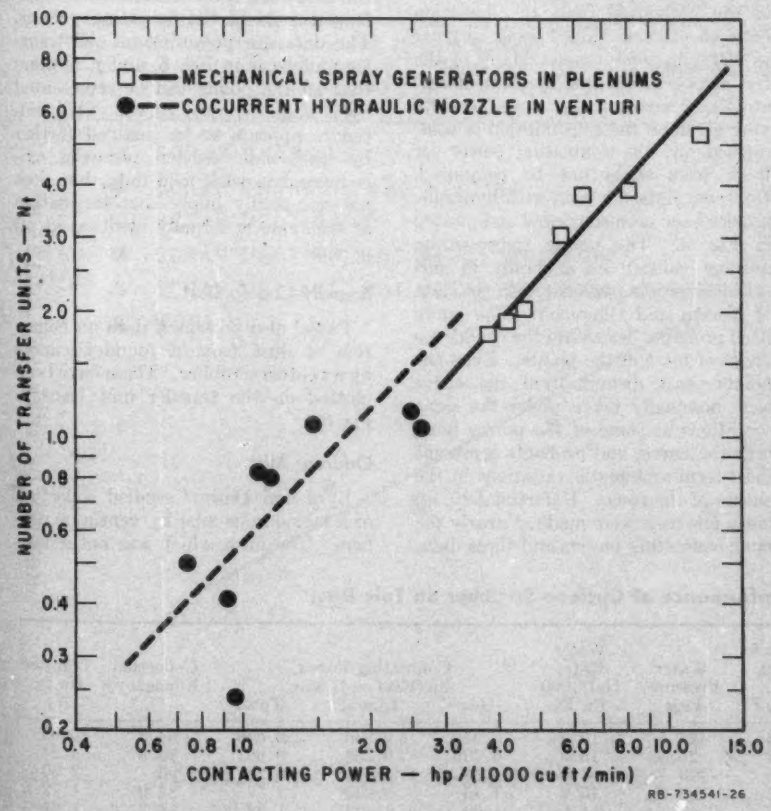

Fig. 2. Performance of solivore scrubber on copper sulfate aerosol.[16]

used, at least if the nozzles are located within the gas stream being scrubbed.

By analogy, the contacting power derived from a mechanical spray generator (such as a spinning disc) is equal to the actual power delivered to the shaft less that consumed in bearing friction.

In a mechanical scrubber (one employing a power-driven rotor or fan), the contacting power is that delivered by the shaft to the gas stream (i.e., the power delivered by the motor less losses in the coupling and bearings) corrected for any increase produced in the pressure or kinetic energy of the gas stream.

The gas flow rate, q_a, could be expressed on a variety of bases. However, the volumetric rate at actual flow conditions appears to be the most logical choice, and has been used throughout this paper and the earlier ones.[17, 22] In Equation 4, q_a has been taken as the arithmetic average of the flow rates at scrubber inlet and outlet conditions. An average gas rate is implicit in Equation 3.

Literature Data

Talc Dust

The method of correlation may be illustrated with the data of Johnson, et al.,[10] who made a laboratory study of collection of talc dust by a cyclone scrubber. A variety of nozzle arrangements and operating conditions were used. Data complete enough for correlation purposes were given only for five runs, and these are shown in Table II. The data points, plotted in Fig. 1, follow the typical relationship discussed above. The deviations of the points from the average curve, which are actually fairly small, are of uncertain significance. Apparently, no replications of the runs were made, and the deviations may reflect the precision of the data.

Copper Sulfate Aerosol

Kristal, Dennis, and Silverman[16] investigated the performance of a Solivore scrubber, a multiple-stage venturi device, using a synthetically generated copper sulfate aerosol. Complete data for individual tests were not given, but could in most cases be estimated from other data presented. No replications of runs appear to have been made, and the precision of the data is therefore unknown.

Originally, the Solivore scrubber was equipped with mechanical spray generators placed in the plenums between the venturi stages. Each generator was driven by a $1^1/_2$-hp motor, but no data were given on the actual power drawn by the generator. Information in the original publication did indicate that, in the runs correlated here, the maximum

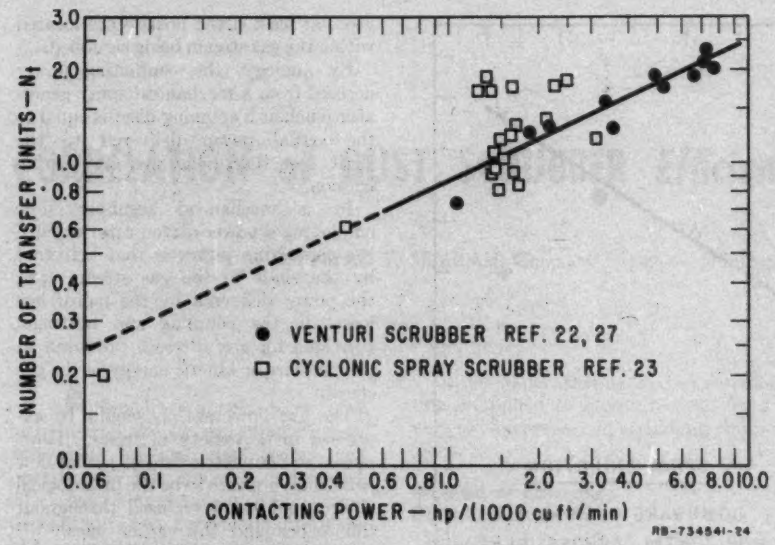

Fig. 3. Performance of scrubbers on ferrosilicon furnace fume.

power of the motor was not developed. For the correlation presented in Fig. 2 it was assumed that the effective power delivered to a generator was 1.0 hp. Allowances were also made for gas pressure drop and hydraulic power. The points represent tests with varying numbers of stages and spray generators, and varied air flows. The absolute value of contacting power is dependent upon the assumption made concerning the power delivered to the spray generators, and an error in the assumption would change all abscissas by approximately an equal fraction (probably not greater than 30%).

A single venturi stage was also fitted with several types of cocurrent hydraulic nozzles operated at various pressures. Data for these tests have also been presented in Fig. 2. The results are less consistent than for the spray generator arrangement, but again the magnitude of experimental error is unknown.

Ferrosilicon Furnace Fume

Yocom and Chapman[27] reported the performance of a venturi scrubber on fume (primarily silica) from an electric ferrosilicon furnace. These data were previously recorrelated,[22] and the points and curve have been reproduced in Fig. 3.

Silverman and Davidson[23] reported performance of a Buffalo Forge cyclonic spray scrubber on fume from a similar furnace. A variety of internal arrangements and spray nozzles was used. At least five test runs were made with each arrangement, and the efficiencies were averaged. Conditions varied widely, and a large spread generally appeared in the transfer units found in the individual runs, the deviation between extreme values being as great as 100% in some cases. Many of the test arrangements employed pneumatic atomizing nozzles, and since no data were given on the consumption of compressed air, the contacting power for these tests could not be computed. However, data for tests with hydraulic nozzles have been computed and plotted in Fig. 3. The points (representing average values) are generally in surprisingly good agreement with the data of Yocom and Chapman. The curve itself probably lies within the confidence limits of most of the points. Even the points most distant from the curve were nominally taken under the same conditions as some of the points lying near the curve, and probably represent short-term systematic variations in the nature of the fume. Unfortunately, all but a few tests were made at nearly the same contacting power, and these data, taken alone, do not show trends clearly.

Phosphoric Acid Mist

Brink and Contant[5] investigated collection of phosphoric acid mist by a plant-scale venturi scrubber. By means of a factorial experiment they demonstrated that increasing the number of spray jets or decreasing the liquid injection velocity significantly increased the efficiency. However, both these trends also coincided with increased pressure drop across the venturi, which would be expected to increase efficiency. The data, correlated on the basis of contacting power (Fig. 4), show no clear trends of efficiency with liquid injection velocity or number of jets which do not coincide also with variations in contacting power.

In Fig. 4, the contacting power includes only venturi pressure drop. The pressure drop across the cyclone was not usually measured, but was only of the order of one in. water,[4] and was generally negligible compared with the venturi pressure drop.

Open Hearth Steel Furnace Fume

Basse[1] presented efficiency data for a pilot plant venturi scrubber operating upon open hearth furnace fume, correlating it on the basis of venturi pressure drop. He showed different curves for different furnace operating periods. However, the sampling periods generally overlapped some of the operating periods. The data are presented on the transfer unit basis in Fig. 5, and it appears that all the points can be represented by a single average curve. This procedure appears to be justified further by the wide scatter normally encountered in such field data, but does not necessarily imply that the nature of the fume is actually identical at all periods.

Foundry Cupola Dust

Basse[1] also presented data on collection of dust from a foundry cupola by a venturi scrubber. These have been plotted on the transfer unit basis in Fig. 6.

Odorous Mist

Byrd and Dewey[7] studied collection of a malodorous mist by venturi scrubbers. The mist, which was not identi-

Table II—Performance of Cyclone Scrubber on Talc Dust[10]

Spray Nozzle Location	Spray Direction	Pressure Drop, In. Water	Water Pressure, Psig	Water Rate, Gal/1000 Cu Ft	Contacting Power, hp/1000 cu ft/min Gas	Liquid	Total	Collection Efficiency, %	Transfer Units, N_t
Cyclone	Downward over inlet	2.6	25.5	15.9	0.410	0.236	0.646	54.8	0.80
	Horizontal, across inlet	4.6	25.5	15.9	0.725	0.236	0.961	70-9	1.24
		8.5	400	8.0	1.34	1.87	3.24	90	2.30
Inlet Duct	Countercurrent	9.2	25	15.2	1.45	0.223	1.67	82.0	1.72
		9.5	50	14.5	1.50	0.422	1.92	84.7	1.88

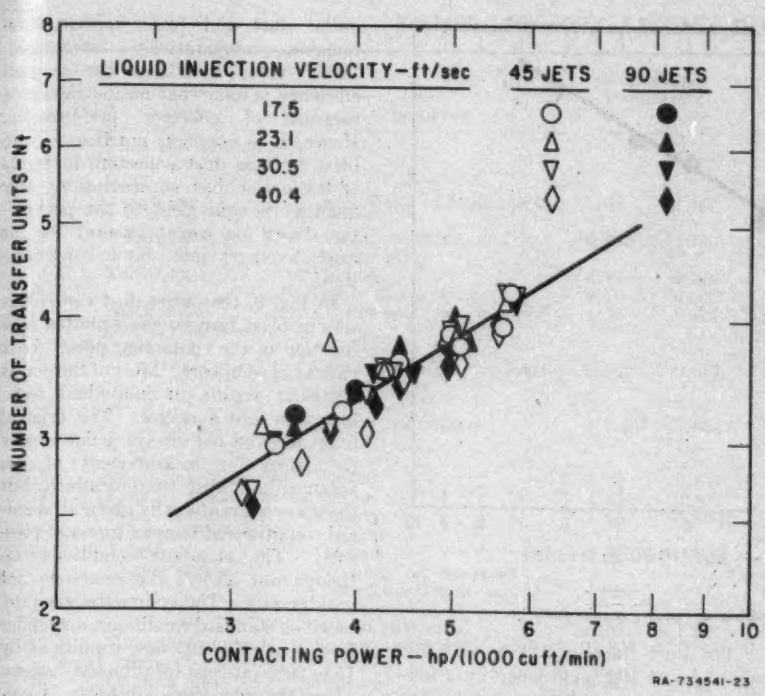

Fig. 4. Performance of venturi scrubber on phosphoric acid mist.[5]

fied, was probably a condensation aerosol formed from vapors of volatilized fats. Efficiency was determined by an odor measurement technique which in effect gave weight collection efficiencies. Byrd and Dewey studied effects of venturi gas velocity and water rate, and presented results in the form of smoothed curves without data points. The points plotted in Fig. 7 were taken from the curves in the original paper[7] and do not represent individual determinations.

Byrd and Dewey concluded that although the efficiency could be correlated primarily on the basis of venturi pressure drop there was some independent effect of gas velocity. However, Fig. 7 does not show any such trend. Considering the scatter in the original data, which must have been greater than that shown here, and also the difficulties of the measurement techniques employed, it is doubtful that the independent effects of gas velocity were of much significance.

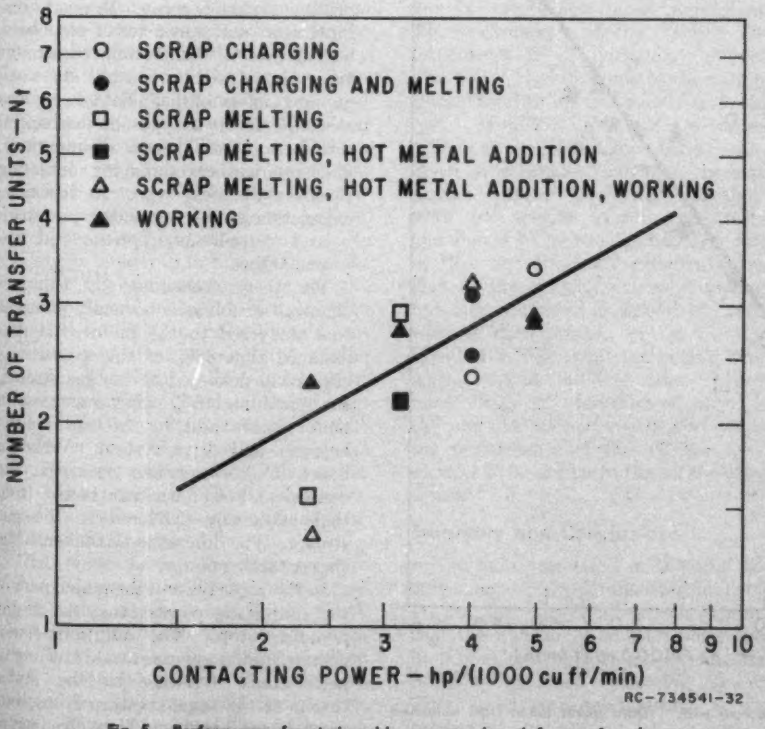

Fig. 5. Performance of venturi scrubber on open hearth furnace fume.[1]

Black Liquor Recovery Furnace Fume

Semrau, Marynowski, Lunde, and Lapple[22] made a study of the performance of pilot plant venturi, pipeline, and cyclonic spray scrubbers on fume from a Kraft (sulfate) black liquor recovery furnace. Data were correlated on the basis of theoretical power input (equal in this case to contacting power). The venturi and cyclonic spray scrubbers, which used cold scrubbing water, gave apparently identical performance. The pipeline scrubber, which used hot recirculated fume solution for scrubbing, gave lower efficiencies than the other two (see Table III). This difference in performance was ascribed to condensation effects obtained with cold water scrubbing. This view was supported by data from the literature on performance of a number of venturi and cyclonic spray scrubbers using hot fume solution for scrubbing. The performance of these latter units closely agreed with that of the pipeline scrubber.

Only one data point (representing average conditions) was available[26] at that time for a venturi evaporator scrubber operating on relatively dry furnace gases and using hot black liquor for scrubbing. This showed an efficiency which was apparently significantly lower than for scrubbing of moist gases with either cold or hot water. It was suggested[22] that the point probably lay on a third performance curve (Table III), and such a curve was drawn through it parallel to the curve for hot water scrubbing. This curve has been reproduced in Fig. 8.

In a recent paper, Stacey[24] has given data on performance of a venturi evaporator scrubber on soda-process recovery furnace fume. These points have been added to Fig. 8, and show very close agreement with the earlier data. They apparently confirm the general location of the curve, but the slope shown can only be taken as a reasonable estimate.

Blast Furnace Dust and Fume

The particulates in gas from iron blast furnaces consist essentially of two components: relatively coarse, mechanically entrained dust, and fine fume formed by condensation of materials

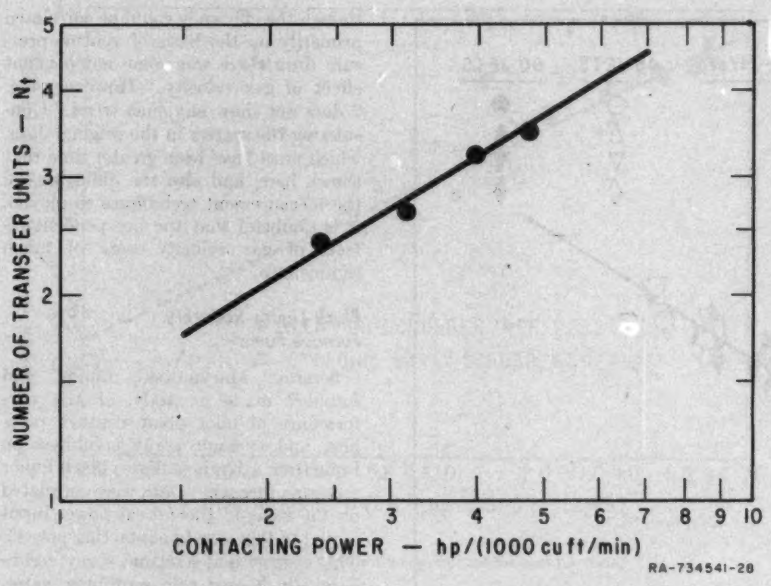

Fig. 6. Performance of venturi scrubber on foundry cupola dust.[1]

volatilized in the hot zone of the furnace. The concentration of dust is normally several times that of the fume, and may vary widely with furnace operation. The concentration of fume also varies widely, though perhaps less than that of the dust.

The dust fraction will be collected with almost 100% efficiency by a low-energy scrubber, and the material in the exit gas will be composed almost entirely of fume. The over-all efficiency is determined primarily by the dust fraction, and may vary widely while the outlet dust and fume concentration remains comparatively unchanged. Under these conditions the over-all efficiency is somewhat meaningless as a measure of collector performance. Hence, it is common practice to rate blast furnace dust collectors in terms of the outlet dust concentration; this quantity is equivalent to the penetration based on some constant (or, at least, average) inlet fume concentration.

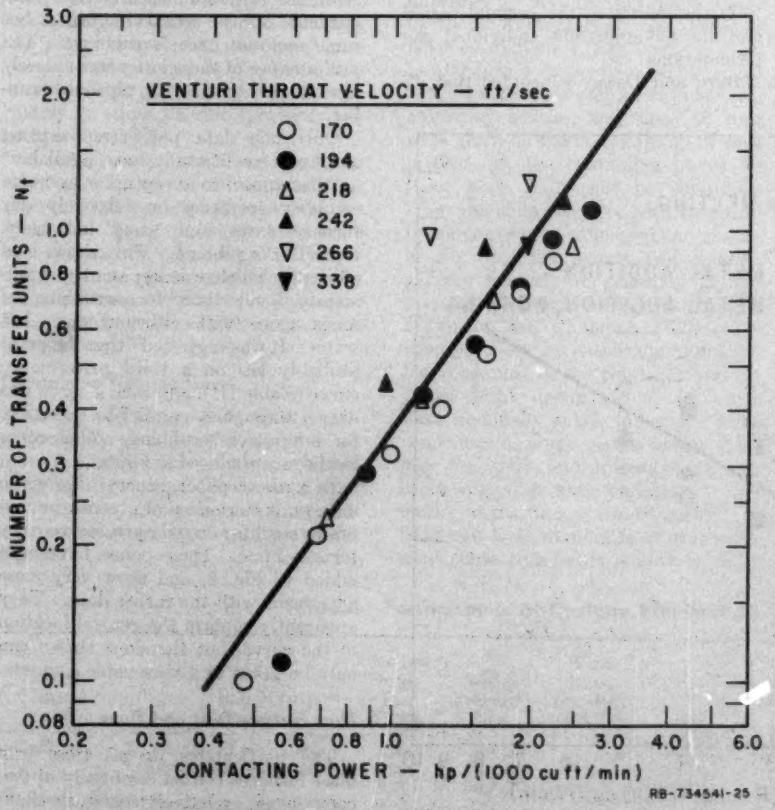

Fig. 7. Performance of venturi scrubber on an odorous mist.[7] (Data points taken from smoothed curves.)

In Fig. 9, the outlet dust concentration in blast furnace gas is plotted as a function of the contacting power for a variety of scrubbers. Most of the points represent results of individual tests, but some are averages. The original references did not always define clearly the bases for measurement of gas volumes and dust concentrations, but these are conventionally given at standard conditions of temperature and pressure. The standard conditions, although not always the same, do not vary greatly. The volumetric gas rate, based on standard conditions, may differ from that at actual flow conditions by 15 to 20% (at least for primary washers, where the inlet gases are hot). A corresponding error may be introduced into the contacting power where the gas rate must be used explicitly in the calculation, but this could have occurred only for three or four of the points shown.

Most of the data shown are for devices in which contacting power is derived from gas pressure drop, hydraulic spray nozzles, or a combination of the two. These include the venturi, orifice, cyclonic spray, Brassert disintegrator, and static tower scrubbers. Calculation of contacting power for these is straightforward. A small amount of published data was also available for two types of mechanical scrubbers: the Theisen disintegrator, and tower washers employing contacting rotors of the Feld type. In this case, calculation of the contacting power involved certain assumptions and approximations.

The power consumed by the mechanical scrubbers is normally given as that delivered to the motor. It was assumed that 85% of this power was effectively delivered to the gas stream, the remaining 15% being consumed in motor losses and by friction in the bearings and drive system. Where a boost in gas pressure occurred, the equivalent power was subtracted from that effectively delivered to the gas stream. The difference was taken to be the contacting power.

In the rotor towers[8] the major part of the contacting power consisted of gas pressure drop. The additional mechanical power appears to add nothing to performance (relative to the static towers at the same pressure drop), but the data are insufficient to be conclusive.

Table III—Summary of Scrubber Data

Curve No. in Fig. 10	Aerosol	Scrubber	Correlation Parameters α	γ	Remarks	Reference No.
	Lime kiln dust and fume (kraft mud kiln)					
1	Raw gas	Venturi and cyclonic spray	1.47	1.05	Lime dust and soda fume	22
2	Prewashed gas	Venturi, pipeline, and cyclonic spray	0.915	1.05	Mostly soda fume	
3-A	Talc dust	Venturi	2.97	0.362	—	17, 22
3-B		Orifice and pipeline	2.70	0.362	—	
4	Black liquor recovery furnace fume	Venturi and cyclonic spray	1.75	0.620	Cold scrubbing water. Furnace gases humid	22
5		Venturi, pipeline, cyclonic spray	0.740	0.861	Hot fume soln. for scrubbing. Furnace gases humid	22
6		Venturi evaporator	0.522	0.861	Hot black liquor for scrubbing. Furnace gases dry	22, 24, 26
7	Phosphoric acid mist	Venturi	1.33	0.647	—	5
8	Foundry cupola dust	Venturi	1.35	0.621	—	1
9	Open hearth steel furnace fume	Venturi	1.26	0.569	—	1
10	Talc dust	Cyclone	1.16	0.655	—	10
	Copper sulfate	Solivore				16
11-A		Mechanical spray generators	0.390	1.14	Power estimated	
11-B		Hydraulic nozzles	0.562	1.06	—	
12	Ferrosilicon furnace fume	Venturi and cyclonic spray	0.870	0.459	—	22, 23, 27
13	Odorous mist	Venturi	0.363	1.41	—	7
	Blast furnace dust and fume	Venturi, orifice, cyclonic spray, tower, disintegrator	—	—	—	1, 3, 6, 8, 12, 13, 14 18, 20, 21, 25

Theisen disintegrators are normally used as secondary cleaners following a primary washer of some type. It is therefore necessary to add the contacting power for the primary scrubber to that for the Theisen to obtain the total contacting power corresponding to the outlet dust concentration. In the paper by Burks[6] data on the primary washers were given, but for the references by Meldau[20] and Rice and Bigelow[21] the needed information could only be estimated. The data of Meldau showed comparatively high inlet dust concentrations, which indicated primary scrubbing by low-energy devices, probably using contacting power considerably under 1.0 hp/(1000 cu ft/min). The contacting power for the primary scrubber was not included with that for the Theisen, since it would constitute only about five to 10% of the latter. The data of Rice and Bigelow were apparently based on an average inlet dust concentration of about 0.25 grain/cu ft, which would correspond to a primary scrubber contacting power of about 1.0 hp/(1000 cuft/min), and this estimated power was added to that for the Theisen.

In some cases, the gas pressure changes across the Theisen disintegrators were relatively small, three-inch water rise to five-inch drop as reported by Burks, and one-inch rise as reported by Rice and Bigelow. The units discussed by Meldau gave large pressure rises, 10 to 17 in. water, corresponding to appreciable fractions of the total power input.

Considering the diversity of the data sources and the limitations of the outlet-concentration method of defining performance, the data plotted in Fig. 9 are in surprisingly good agreement. The performance of the Theisen disintegrators is of particular interest. The points corresponding to the data of Burks[6] tend to deviate widely from the rest. However, the average power consumptions listed by Burks were given as estimates, and were perhaps nominal values. The data of Meldau[20] were for specific performance tests, and should be more reliable. The data of Rice and Bigelow[21] presumably reflect results of fairly extensive testing, but were presented as smoothed curves without data points. They are represented in Fig. 9 by the broken line, whose length indicates the approximate range of conditions reported in the original reference. On the whole, the performance of the Theisen units appears to be similar to that of the other types.

Summary and Conclusions

The data correlated in this and the earlier paper[22] are summarized in Table III and Fig. 10. In all cases it is found that the number of transfer units may be represented by a simple exponential function of the contacting power. This functional relationship is expressed by:

$$N_t = \alpha P_T^{\gamma} \qquad (5)$$

where P_T is the total contacting power and α and γ are constants characteristic primarily of the aerosol. It would be expected that γ should be related primarily to aerosol particle size distribution, whereas α should be related to both particle size and size distribution. This type of relationship was found to hold very closely for data of good precision obtained under laboratory conditions.[17, 22] In all other cases it appears to hold over the range of practical interest.

A logarithmic plot of penetration as a contacting power may show considerable curvature,[17] particularly at low values of contacting power. It may be approximately linear in the higher contacting power range, as in Fig. 9.

Correlation of the literature data generally confirms the findings of the earlier studies[17, 22] on the relationship of efficiency and contacting power. Efficiency is found to have little relation to scrubber design and geometry, but to be dependent on the properties of the aerosol and on the contacting power. There are few data to show the effect of scrubber size, but a number of the studies cited[1, 2, 7, 17, 22] report that there are essentially no scale effects.

The data specifically support the earlier observation[22] that contacting power derived from hydraulic spray nozzles is equivalent to that derived from gas pressure drop. There are no

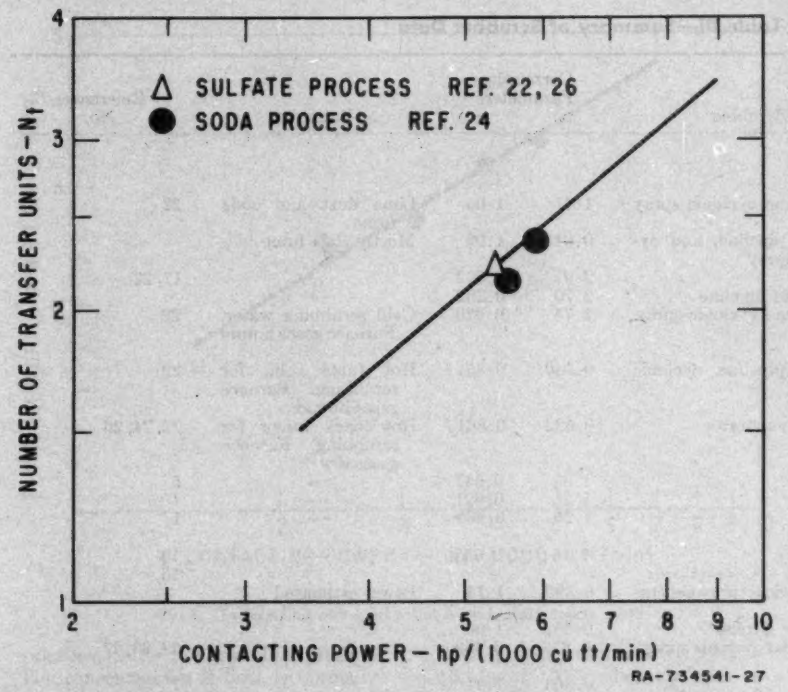

Fig. 8. Performance of venturi evaporator scrubbers on black liquor recovery furnace fume

data available to test the hypothesis that contacting power from pneumatic spray nozzles is also equivalent. The available information is insufficient to demonstrate unequivocally that contacting power supplied mechanically is equivalent to that derived from gas pressure drop or hydraulic spray nozzles. However, it does strongly indicate that such may be the case.

Note: Material supplementary to this article has been deposited as Document number 6300 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the Document number and by remitting $2.50 for photoprints, or $1.75 for 35 mm microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.

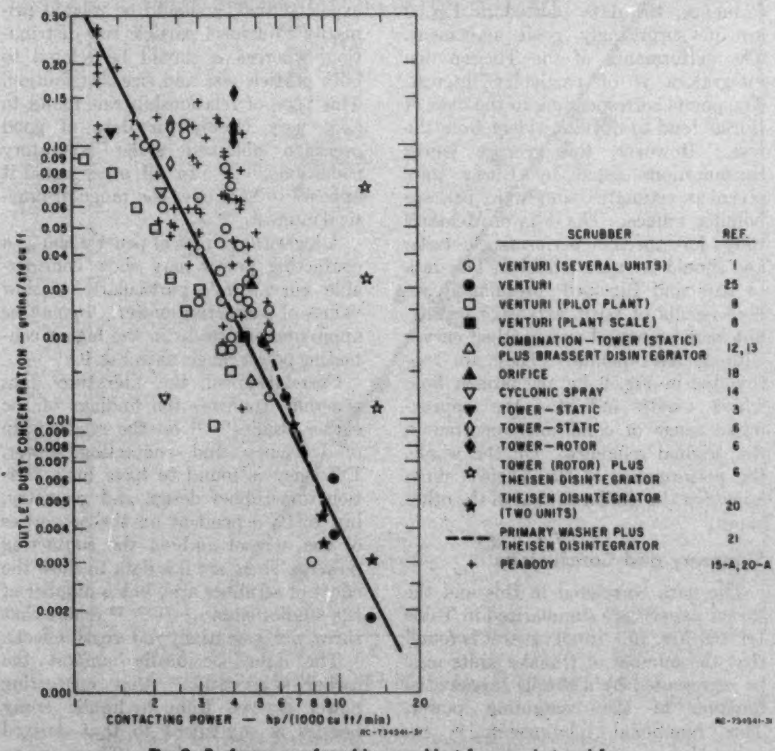
OUTLET DUST CONCENTRATION – grains/std cu ft
CONTACTING POWER – hp/(1000 cu ft/min)
SCRUBBER
REF.
VENTURI (SEVERAL UNITS) 1
VENTURI 25
VENTURI (PILOT PLANT) 8
VENTURI (PLANT SCALE) 8
COMBINATION – TOWER (STATIC) PLUS BRASSERT DISINTEGRATOR 12, 13
ORIFICE 18
CYCLONIC SPRAY 14
TOWER – STATIC 3
TOWER – STATIC 6
TOWER – ROTOR 6
TOWER (ROTOR) PLUS THEISEN DISINTEGRATOR 6
THEISEN DISINTEGRATOR (TWO UNITS) 20
PRIMARY WASHER PLUS THEISEN DISINTEGRATOR 21
PEABODY 19-A, 20-A

Fig. 9. Performance of scrubbers on blast furnace dust and fume.

Acknowledgement

The author is grateful to R. Kopita (Peabody Engineering Corp.) and J. A. Brink, Jr. (Monsanto Chemical Co.). for permission to use unpublished data.

Nomenclature

- F_s = friction loss across unit, in. water
- N_t = number of transfer units, dimensionless $= \ln\left(\frac{1}{1-\eta}\right)$
- p_F = liquid feed pressure, lb force/sq in., gage
- Δp = gas pressure drop across unit, in. water
- P_G = contacting power derived from the gas stream, hp/(1000 cu ft/min)
- P_L = contacting power derived from hydraulic spray nozzles, hp/(1000 cu ft/min)
- P_T = total contacting power, hp/(1000 cu ft/min)
- q_G = gas flow rate, cu ft/min
- q_L = liquid feed rate, gpm
- α = constant of Equation 5, [hp/(1000 cu ft/min)]$^{-\gamma}$
- γ = constant of Equation 5, dimensionless
- η = collection efficiency, fraction of influent aerosol collected by scrubber
- $1-\eta$ = penetration, fraction of influent aerosol escaping collection

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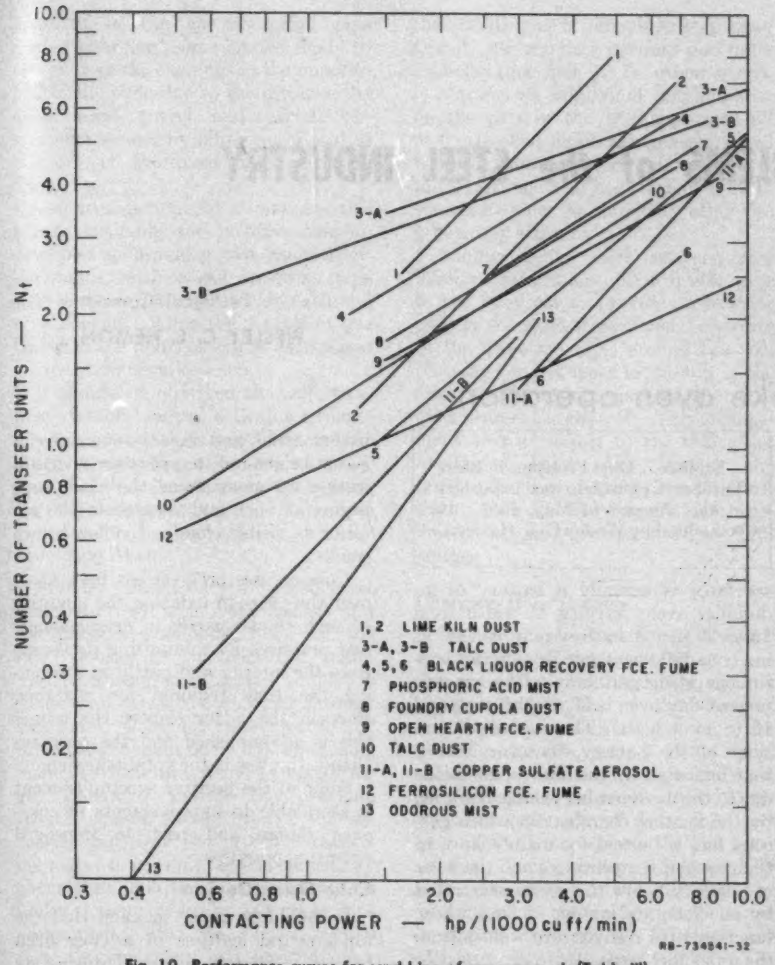
NUMBER OF TRANSFER UNITS — N_t
CONTACTING POWER — hp/(1000 cu ft/min)
1, 2 LIME KILN DUST
3-A, 3-B TALC DUST
4, 5, 6 BLACK LIQUOR RECOVERY FCE. FUME
7 PHOSPHORIC ACID MIST
8 FOUNDRY CUPOLA DUST
9 OPEN HEARTH FCE. FUME
10 TALC DUST
11-A, 11-B COPPER SULFATE AEROSOL
12 FERROSILICON FCE. FUME
13 ODOROUS MIST
RB-734841-32

Fig. 10. Performance curves for scrubbing of some aerosols (Table III).

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TO OUR READERS:

We wish to direct your attention to Gulf Oil Corporation's ad which appears on the back cover of this issue. The message is directed primarily to the men who write and interpret the news. Obviously Gulf's objective was to acquaint the press with work being done in one important area of our Association's interest—namely, refineries and motor vehicles as sources of air pollutants. It is believed that the information this ad sets forth will contribute to a better understanding of some of the problems we face. Other public relations advertisements of this nature are encouraged in the "Journal."

REDUCING EMISSIONS FROM INCINERATORS

(*Continued from page 197*)

solidated Edison Co. of N. Y. The Werner Air Pollution Controls, Inc., installed the Werner Device. The Hartmann Device was fabricated and installed by the R. G. White Manufacturing Corp., Ozone Park, New York. The inventors were both helpful in advising on the use of their equipment.

M. M. Braverman, I. Ettinger, S. Hochheiser, B. H. Pearson, and C. Theophil of the Bureau of Laboratory, Department of Air Pollution Control, New York City, conducted the sampling and determination of noxious gases and the analysis of particulate matter. Joseph Mankovitz and George Tipikin of the Department assisted with the tests.

Daniel Marchi, assistant research scientist; Robert Fatell and James Jeffress, senior research aides; and Mrs. Sylvia Friedman, research aide, assisted in fabricating equipment, conducting tests, and in calculations.

The encouragement and advice of Associated Dean Harold K. Work, Director, Research Division of the College of Engineering, and of Commissioner Leonard Greenburg, Deputy Commissioner Sylvan Hanauer, and Chief Engineer Leo P. Flood of the Department of Air Pollution Control, City of New York, deserve special mention.

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(*Continued on page 251*)

AIR POLLUTION PROBLEMS *of the* STEEL INDUSTRY

Informative Report

Technical Committee TI-6

WESLEY C. L. HEMON, Editor

Section II—Smoke in coke oven operation

Coke for smelting of iron ore in the blast furnace must meet particular specifications as to its physical qualities and composition and is especially produced in the coke oven plant from carefully selected types of bituminous coal.

The wasteful and outmoded beehive coke oven which is operated occasionally in some districts during periods of high demand for metallurgical coke, as in time of war, produces excessive amounts of smoke. Because of the inherent nature of this equipment such smoke cannot be reduced. The only measure of control, therefore, is in restrictions respecting location of such ovens in relation to built-up communities. The remainder of this discussion is confined to the modern by-product coke oven.

The selected coals are sized by crushing and pulverizing, blended according to formula, and transported to coal storage bins above the coke ovens. Measured quantities of the coal blend are removed from these bins into a larry car which runs on a track running along the top of the coke oven battery.

The larry car then moves to an empty oven and its measured contents discharged into the oven interior.

During the coking cycle, volatile gases released from the coal charged are conducted through a system of pipes to the by-product plant where, in a series of processes, constituents of value are recovered from the raw gases and the final, stripped coke-oven gas piped to some other equipment and burned as fuel.

At the end of the coking cycle, the coke formed in this carbonizing process is discharged from the oven into a quenching car whence it is transported to the quenching station where the incandescent mass is quenched with a very large quantity of water.

Subsequently the quenched coke is discharged onto the coke wharf, allowed to cool, and then transported to screening and crushing equipment.

Description of Coke Ovens

The large masonry structure recognized as coke ovens by the passing spectator is actually a battery of individual ovens varying in width from 15 to 20 in. A battery may include as many as 100 ovens side by side in a continuous structural unit. The average present-day oven is 30 to 40 ft long and 10 to 14 ft high. The over-all dimensions of the battery, however, exceed that indicated by the above dimensions due to the considerable volume occupied by the heating chambers in which gaseous fuel is burned for maintenance of the required temperatures and the mass of masonry below the ovens penetrated by an elaborate system of flues whose function is to recover heat values from the waste fuel gases.

Section I, Dust Problems in Blast Furnace Operation, was published in this *Journal* in May, 1957. It was edited by Wesley C. L. Hemeon.

Sources of Atmospheric Pollution

Visible smoke or other emissions around a by-product coke oven plant originate from the following operations: (*a*) charging of coal into the ovens; (*b*) leakage during carbonization; (*c*) pushing the coke out of the ovens; and (*d*) quenching the hot coke.

The following discussion does not include such purely in-plant problems as coal dust incident to the grinding and blending of coal, and steam and dust at the coke wharf. Also omitted from the discussion are the fuel-burning processes for the generation of steam, e.g., the burning of the coke breeze (the fine particles of coke too small for use in the blast furnace) and of the coke oven gas which, as a by-product, may be utilized as fuel in any of several other processes in the steel plant.

Smoke and Gases in Charging Coal into Ovens

Soon after an oven has been emptied of coke at the end of the coking cycle, it is refilled with a new charge of pulverized coal which may range in size from three-inch lumps down to pulverized material, and since the oven interior is at bright-red temperature, volatilization of gases from the coal mass begins at once and escapes to the exterior as visible clouds of yellow-brown smoke.

Considerable progress has been made over the years in reducing the quantity of such smoke partly in arrangements and practices for minimizing its escape from the interior and partly in shortening the time required for charging, since in the latter respect the sooner this is accomplished and the openings closed, the less is the total emission.

Some of the positive accomplishment is ascribable to improvements in coke-oven design and part to improved operating practices.

Coke Oven Design

It should be borne in mind that the fundamental features of a coke oven battery cannot be changed during its lifetime, which amounts to 20 to 30 years. At the end of its life it is completely razed and a new structure erected to replace it. At such times new features of design are inevitably incorporated both for improved economy of operation and air pollution control.

Steam Jet Aspiration

A number of newer design features have been under discussion in recent years on some of which there is general agreement and on others differences of opinion prevail within the industry. Leech[1] discusses a number of these and brings out the fact that one important improvement over older practice includes facilities for aspirating gases from the interior of the oven during charging by means of steam jet aspirators in the ascension pipe elbow, whereas in former times it was the practice to seal off the oven interior from the gas-collecting main during charging. This resulted in the emission of enormous quantities of smoke during this period in comparison with that under current practice.

Double Collecting Main

Even though a steam jet aspirator is

operated in the gas ascension pipe during charging, some smoke tends to escape from the openings at the opposite end of the oven due to the distance the gases must travel and partial obstruction caused by piling up of coal as portions of the oven become nearly filled.

One arrangement for minimizing this effect, available for incorporation in new plants, provides two gas collecting mains, with a gas ascension pipe with a steam jet aspirator at each end of the oven. Thus the length of gas travel to the point of exit is halved and escape of smoke is lessened.

It should be observed that effectiveness of smoke control with this arrangement is also greatly dependent on the charging operators who must manually open and close the steam valves supplying the jet aspirators.

Equalizing Main

Another design feature somewhat similar to the double main consists in a gas pressure equalizing main on the side opposite to the collecting main. The equalizing main serves simply to connect all ovens to each other through this main; it is not connected to the principal gas main flue. The equalizing main provides an avenue of egress for gas generated during the charging (which cannot leave through the ascension pipe into the principal collecting main) to pass into one of the nearby ovens that, due to its coking stage, is under lower pressure and can thus accommodate this gas. This arrangement is somewhat less positive and, therefore, less effective than the double main.

Special Duct By-Passes Attached to Larry Car

Various ideas have been advanced to provide additional gas passageway from the interior of ovens being charged supplementing that provided by a single ascension pipe leading to the gas main, i.e., to accomplish less expensively the effect of a double gas collecting main or an equalizing main. One of these proposes to take advantage of the lower pressure existing in adjacent partially coked ovens. To this end, a smoke duct fixed to the larry car assumes a position when the car is located for charging such that it provides a passage for gas from the end of the oven being charged that is farthest from the ascension pipe (and hence more likely to permit escape of smoke) to the top interior of an adjacent oven which is under lower pressure. In this arrangement a steam aspirator in the gas uptake of the adjacent oven would be turned on to increase the flow of gases. Leech, discussing this arrangement, draws attention to the disadvantages; the "smoke pipe is difficult to keep clean and its use requires opening one more coal-charging hole." In other words, it requires an additional manipulation on the part of the workman with all of the implied disadvantages concerned with the human factor. Improvements in this arrangement may be hoped for in the future since its simplicity otherwise is basically attractive.

Another device which has been tried involves attachment of a bustle pipe to the larry car to provide an exterior passage for gases from the end opposite to the ascension pipe, around the coal blocking the gas space in the top of the oven, to the interior space of the same oven nearest the gas exit. This arrangement also is subject to the difficulties mentioned above, i.e., keeping the bustle pipe free of tarry deposits tending to plug it. Here again future development may overcome these difficulties.

Charging Hole Spacing

One of the coke oven design elements that minimizes the escape of smoke from the oven interior during charging is in appropriate spacing of the charging holes in relation to oven volume. The objective in this respect is to avoid piling up of coal anywhere in the oven in such manner as to create a barrier to the free passage of gases from any part of the oven toward the gas takeoff flue. This condition is attained by calculated spacing of the charging holes in relation to the volume of the oven, a feature discussed by Wilputte and Wethly[2] and also by Leech.[1] The latter refers also in this same connection to the advantage resulting from the design arrangement in which the bottom ends of the charging holes where they enter the oven chamber are flared outward, thus providing more gas space between the coal charge and the top of the oven for free passage of gases.

Sleeves and Shear Gates

Another feature that has received attention in recent years aims to provide an enclosure between the hopper of the larry car and the top of the charging opening to prevent the escape of smoke-laden gases from the oven interior during the charging. This takes the form of drop sleeves and shear gates, which allow the operator to lower the sleeve to the top of the oven preparatory to charging the coal and to close the gate of each hopper as soon as it has been emptied, the latter to prevent the passage of gases upward through the hopper.[3] Immediately following this operation the operator will trip the drop-sleeve to raise it and quickly replace the lid. Then the leaks around the charging-hole lid are sealed either by luting or by dry seal.

Coal Measuring Sleeves

Since a part of the problem of allowing free passage of gas from one end of the oven to the other, during charging, is related to the volume of coal charged from a given hopper, attention has been given to means for better control and that has resulted in the development of volumetric sleeves on the top of the larry car hoppers which make it possible to adjust the bulk of coal in each hopper to match the requirements of ovens of different cubical capacity. This device makes it possible to charge the correct volume of coal and thus minimize the gas passage difficulties discussed above.

Mechanical Feed from Car to Oven

Any arrangements which reduce the time required for transfer of the coal charge from larry car hopper to oven interior will reduce the total escape of smoke and several mechanical devices have been advanced toward this end, including hopper vibrating mechanisms in conjunction with smooth stainless steel liners, cylindrical hoppers and bottom turn-table feeders, and a screw feed mechanism. The industry is attentive to these new developments and can be expected to adopt one or another as experience points the way to the best of these.

Control of Coal Bulk Density

Control of the bulk density of the coal mass is one of the factors contributing to coal feed rate as well as to certain production aspects. In those operations where the coal is pulverized and blended it has become increasingly common to control the moisture content and, by addition of small quantities of oil to the coal, to modify the bulk density further. Leech observes that oil-sprayed coal moves out of the larry car hoppers with much greater facility, thus reducing time required for charging.

Leveling

During the oven-charging process, the leveling operation ensues which involves operation of the leveling bar, a mechanism that is an element of the coke pusher equipment, operating through the leveling bar opening on the pusher side, near the top of each oven. Operation of the steam jet aspirator in the ascension pipe of the oven being serviced tends to prevent the escape of much smoke from the oven interior but it is not entirely successful. To perfect the control of smoke at this point, each oven can be equipped with a smoke seal box surrounding the leveler bar opening and which, in conjunction with the effect of the steam jet aspirator, and which, in conjunction with the effect of the steam jet aspirator, will greatly reduce the escape of gas from

this opening, and on batteries having a gas-collecting main on the pusher side, practically eliminates all escape of smoky gases.

Carbonization Period

During the 18- to 20-hr carbonization period, leakage of smoke from the interior of an oven may occur around the doors unless measures are adopted to minimize it.

Sealing of Oven Doors

In older designs the joint between the coke oven door and the jamb is sealed by luting, in a hand-troweling process, a wet mixture of clay and coke breeze into a channel between the door and the jamb. In recent years a number of self-sealing door designs have appeared in which metal-to-metal contact between a machined surface and a knife edge, together with mechanical arrangements for exerting pressure, provides the seal and avoids the disadvantages of the older luting method which is so dependent for its effectiveness on the attitude of the workmen having this responsibility. It is, however, necessary that a superior maintenance program be applied to this equipment since wear and tear inevitably allows the development of leakage.

An optimum maintenance program for self-sealing doors, as proposed by coke oven operators of Allegheny County, Pennsylvania[3] includes changing the knife-edge material to stainless steel; adoption of a numerical system whereby a complete history of each door is kept, and of a system of tagging of doors by the operators to inform the maintenance force of the reason a particular door was taken out of service.

As to luted doors, it is advocated that tamping of the luting after completion of charging be practiced to minimize smoke emission from that source.

Pushing

At the end of the coking cycle the incandescent coke is transferred from the oven by pushing equipment into the coke-quenching car. The quantity of smoke arising from the mass during the period required for transport to the quenching station is dependent on the degree of coking. Incompletely carbonized coke ("green" coke) gives rise to considerable quantities of smoke; and conversely, if thoroughly carbonized, very little smoke is produced.

Coke Quenching

In the quenching process a car of incandescent coke, holding as much as 14 tons, fresh from the oven, is transported rapidly to the quenching station where the mass is quenched with some 4000–6000 gal of water in a short period of a minute and a half. Vast clouds of resulting steam soar upward from the tower and are visible for great distances.

Some liquid water droplets are entrained in the high velocity currents of air and steam inside the tower and are often perceptible as a light rain or mist within a radius of a few hundred feet. There is also the possibility of entrainment of fine particles of coke but the quantity is small, and, like the water droplets, tend to be deposited on the ground within a short distance of the tower. Contrary, therefore, to common opinion, the coke quenching tower is not a significant source of air pollution insofar as the neighborhood is concerned even though it may cause metal corrosion problems within the plant where contaminated water is employed for the quenching liquid.

Section III—The open hearth furnace

The open hearth furnace is the unit in which some 90% of the steel made in the country is produced. In a process which is superficially simple but intrinsically rather complicated, the pig iron produced in the blast furnace is transformed into steel by means which reduces the carbon content of four to five percent in the pig iron to a fraction of one percent and, equally essential in modern steel-making practice, controls the content of ever-present phosphorous, sulfur, manganese, and silicon.

Groups of furnaces up to a dozen or so arranged in a row comprise an open hearth shop. The open hearth shop is completely housed in a mill building identifiable from the outside by its row of steel stacks relatively closely spaced, looming some 50 to 100 ft above the roof line of the main building emitting vari-colored smoke ranging from white through various shades of tan.

The furnace proper consists of a shallow rectangular basin or hearth enclosed by walls and roof all constructed of refractory brick, and provided with access doors along one wall adjacent to the operating floor. A tap-hole at the base of the opposite wall above the pit is provided to drain the finished molten steel into the ladles.

Fuel in the form of oil, tar, coke oven, or natural gas, or producer gas is burned at one end. The flame from combustion of the fuel travels the length of the furnace above the charge resting on the hearth. The hot gases on leaving the furnace interior are conducted in a flue downward to a regenerative chamber for heat recovery consisting in a mass of refractory brick systematically laid to provide a large number of small passageways for the hot gas called checkerwork or checkers. In passing through the checkerwork the brick mass absorbs heat, cooling the gases to around 1200°F.

All the elements of the combustion system—burners, checkerwork, and flues are duplicated at each end of the furnace which permits frequent and systematic reversal of flow of the flame, flue gases, and pre-heated air for combustion. A system of valves in the flue effects the gas reversal so that the heat stored up in checkers is subsequently given up to a reverse direction stream of air flowing to the burners.

In some plants, the gases leaving the checkerwork pass to a waste heat boiler for further extraction of heat which reduces the temperature from around 1200°F to an average of 500° or 600°F.

Operation

Open hearth furnace capacities span a wide range. The median is between 100 to 200 tons per heat but there are many of smaller capacity and an increasing number of larger capacity. Time required to produce a heat is commonly between eight and 12 hours.

Raw materials charged to the open hearth furnace besides pig iron include iron ore, limestone, scrap iron, and scrap steel; and each of these is employed in different forms. The pig iron may be molten or in the form of cold pigs. The iron ore may be fine or in lumps and the scrap metal in a considerable variety of forms. The proportions of various ingredients vary with economic circumstances, with the characteristics of material supply and numerous other factors that need not be detailed here. The proportioning of metals and auxiliary materials, the order and the timing of their addition is complex and dependent for example, on the kinds of materials available, the kind of steel to be produced, characteristics of the fuel and of the furnace, and calls for a high order of skill from the open hearth furnace operator.

Stack Emissions

The solids in the flue gases of open hearth furnaces include both coarse and fine particles and are continually emitted at highly variable rates throughout the eight to 12-hour cycle of an open hearth heat, variable in color appearance as well as in quantity. These particles originate from the mechanical and chemical reaction of hot gases inside the furnace on the charged materials, from the chemical reactions and agitation in the molten

Table I—Dust Collection Efficiency on Open Hearth Fumes of Several Inertial Type Dust Collectors (According to Vajda)

Type W Rotoclone	45%
Multiclone (6 in. tubes, 4 in. pressure drop)	43%
Type N Rotoclone (4 in. pressure drop)	50%
Pebble filter (Two 4 in. beds 1/8 in. to 1/2 in. pebbles 6 in. pressure drop	78%

bath itself, and from the combustion of the fuel. In addition to the dust and fume, gaseous emissions result in quantities determined by the composition and rate of fuel combustion.

Available data indicate that the highest rate of solids emission occurs in the first half hour after hot metal addition, and the period of one to two hours in the latter part of the ore boil. In the remaining period comprising more than 80% of the cycle, the solids emission rate is materially lower. The overall average concentration of solids in the flue gases is approximately 0.4 grain per cubic foot measured at standard conditions. This amounts to approximately five to 10 pounds of solids per ton of steel dependent upon the type of furnace operation. Over half the dust is less than one micron in size and a large part of this material has been measured at about 0.03 micron.

Flues and Checkers

During the course of furnace operation, coarser particles carried out of the furnace settle out in the flues and in the checkers. In order to avoid choking of these passages, it is necessary periodically to clear them and this is done by blowing with large volumes of steam for short periods of time, three or four times a month. The quantity of such dust is a minor proportion of total solids although it escapes into the open atmosphere in a relatively short period of time, and being composed of relatively coarse material would have a greater tendency to settle rapidly out of the atmosphere.

Fume Control

Engineering methods for the reduction of solids emission from open hearth furnaces have been the subject of extensive inquiry and investigation by the industry in recent years. This problem has been one of the most troublesome for the steel industry because of the design and operating difficulties encountered with precipitators, their high cost, and because many plants do not have adequate ground space near the open hearth stacks to permit installing such bulky equipment.

These difficulties have impelled the industry to support exploratory studies seeking possible alternatives. One of these was an extensive pilot investigation by Vajda[4] in Pittsburgh which included studies of the performance of various types of commercial scrubbers and inertial dust collectors. The findings indicated that a number of common types of equipment were capable of removing 50 to 60% by weight of these solids which, it should be pointed out, is that fraction which contributes to the dustfall nuisance of a community.

These are the efficiencies during furnace heats. The efficiency during blowing of flues and of checkers would be much higher because that dust consists mainly of coarse particles. No industrial installations of these types have been made.

Performance Criteria

What criteria of performance are properly applicable to open hearth flue gas cleaning?

One kind of criterion would cite the maximum permissible concentration of solids in the stack gases. Municipal regulations apply this basis widely to solid fuel burning equipment. When one comes to the consideration of an actual concentration figure to apply to open hearth furnace gases as a definition of good practice, there are various opinions as to what criteria should govern.

One view is summarized in the following. Decisions should not be based simply on the appearance of the stack plume. Specifications should rather be based on the concept that fume removal equipment ought to be of such efficiency that residents in the neighborhood are not subject to perceptible increments of dustfall on their premises. If such a standard were to be applied to the framing of a dust collection performance code for open hearth furnaces a number of inertial-type dust collectors and scrubbers would render acceptable service in many cases even though weight efficiencies would not exceed 50% during normal heats and perhaps over 90% during blowing of checkers and flues. The reason for this is that such collectors effectively remove the largest particles and these are the ones which may cause annoyance if they are deposited at ground level at a perceptible rate.

Another view expresses the conviction that the appearance of the stack plume should serve as the ultimate criterion. The argument in support of this is that unless fume is removed from the stack gases in amounts sufficient to dissolve the plume so that improvement is visually obvious to neighbors and passersby, the effort will have been wasted, since people are prone to complain on the basis of what they see at the stack even though there be no relationship to effects at ground level.

This attitude, representing as it does the line of least resistance, may be valid from the psychological viewpoint but not so from a scientific one. It is nevertheless widely held and was the basis on which Vajda rested his conclusions concerning the performance of various types of gas cleaner tested by him. He remarked, "Experiments... indicate that the outlet dust loading must be down to 0.05 grain per cubic foot to give a clear stack. Above this loading, a bystander cannot tell whether there is a cleaning unit on the stack or not."

Electric Precipitators

Electric precipitators have been installed (1959) for open hearth stack gas cleaning in steel plants at Geneva, Utah; Torrance and Fontana, Calif.; at Morrisville, Pa. and plans for installation have been announced by two companies in the Pittsburgh area. The Geneva installation differs from the other three in that provisions for supplemental fluoride control were incorporated in the design. This was accomplished by injection of lime into the gases to react with the gas-borne fluorides at a point preceding the precipitators. Therefore in this case the precipitators remove both particulate matter and the solid fluoride compounds formed by the above reaction.

Two points of importance need to be observed respecting electric precipitators. A visible, ever conspicuous plume is still apparent even when precipitators are operating at 90% efficiency and greater, a point having a bearing on the question of criteria discussed above.

The other point concerns the considerable experimental effort that is required after a precipitator is installed, to develop it to a stage of satisfactory performance. Electric precipitation of open hearth dust is still more of an art than a science. The engineering problems are well illustrated in the article by Akerlow[5] which details the development work over a period of several years that was involved in discovering causes of imperfect operation and designing corrective measures.

Filtration Research

Paralleling the developments described above, the American Iron and Steel Institute, recognizing the importance of this problem, in 1953 initiated research at the Harvard School of Public Health under Dr. Leslie Silverman seeking to ascertain the feasibility of filtration through slag wool in conjunction with a process for

rejuvenation of the filtering media. A pilot unit has provided data leading to hopes that a gas cleaning apparatus might be developed requiring minimum ground area. This research is continuing.

Section IV—Bessemer and Top-blown Converters

Pneumatic converters serve basically the same function as that of open hearth furnaces, i.e., the transformation of pig iron to steel by lowering of the carbon, silicon, and manganese content according to the desired quality of the finished steel.

The refractory-lined steel vessel receives a charge of molten pig iron in quantities ranging from 25 to 30 tons in the case of the older Bessemer converters on up to double or more that quantity in more recently constructed units. Elimination of the dissolved carbon is effected by oxidation which results from intimate contact with a stream of air or oxygen. Since in a typical charge of pig iron the dissolved carbon, silicon, and other elements upon oxidation is equivalent in heating value to one ton or more of coal, no auxiliary fuel is required in this type of smelting; all that is required is a supply of oxygen to the molten charge.

Pneumatic converters of 30 tons capacity effect the complete oxidation reaction in a brief period of 10–15 min in contrast to the open hearth furnace where the melting and refining of 100–200 tons of steel requires periods ranging from eight to 12 hours. The advantages apparent in the preceding statement tend to be counteracted in some degree by a number of considerations. These include the composition of the resulting steel respecting such trace elements as phosphorus, sulfur, nitrogen, oxygen, etc. in relation to the metallurgical qualities of the resulting steel which in turn are determined by the physical qualities required in subsequent fabrication. These considerations in turn are related to the quality of raw materials, e.g., iron ore. A factor of importance in a comparison of the function of Bessemer converters vs. open hearth furnaces is in the limited extent to which these converters can melt scrap metal.

The relatively low capital investment required for pneumatic converters in combination with their other advantages has led recently to a period of extensive engineering and metallurgical research to find ways of more effectively exploiting these advantages.

Bessemer Converters

Bessemer converters are those spectacular steel-making units whose brilliant yellow flame dramatically illuminates the sky around some steel plants at night and which discharge volumes of high-soaring clouds of orange-brownish iron oxide fumes prominently visible in daytime.

They are cylindrical steel vessels with a spout or nose surmounting the top at an angle with the main axis, mounted on trunnions on which they can rotate. One of the trunnions is hollow and serves as an air duct for passage of air from a blower to a chamber at the bottom of the vessel known as the wind box.

Air passes upward (when the converter is vertical) into the molten metal through holes (tuyeres) in the refractory barrier separating the wind box from the molten metal bath. Air pressure prevents metal from trickling downward through the tuyeres into the wind box. When the converter is tilted 90° on its side the surface of the molten metal is below all tuyeres and the air blast can be shut off when it is in this position. In fact this is the position of the converter when it is charged with molten pig iron.

The sequence of operations in the operation of a Bessemer converter is well outlined in the following extract:[6]

"After completion of the previous blow, the vessel is turned on its trunnions until it assumes an almost horizontal position and scrap, scale, or ore is dumped into the vessel if desired. The molten pig iron is then poured in from the transfer ladle. In this horizontal position the metal is contained in the belly of the converter and does not come in contact with the tuyeres. The blast is started and the vessel turned to a vertical position and remains in this position throughout the balance of the blowing period, unless 'side-blowing' is resorted to for increasing temperature.

"The Bessemer blow is usually thought of as being divided into three parts, the first period, the second period, and the after blow.

"The first period, or the *silicon blow*, as it is commonly called, begins as the blast is turned on and the vessel turned up. During this period of the blow, a short transparent flame extends from the mouth of the vessel. As the blowing continues the flame starts to lengthen after about four minutes and the second period or *carbon blow* begins.

"It is during the second period that the flame attains its full brilliance and length, extending as much as 30 feet beyond the mouth of the converter. This flame results from the evolved carbon monoxide burning to carbon dioxide as it comes in contact with the air at the mouth of the converter. It is at this time that the blower carefully studies the flame to determine if his judgment regarding temperature control, and in estimating the amount of scrap needed, initially was correct.

"The long, brilliant flame which is characteristic of the carbon blow continues until the elimination of carbon approaches completion, whereupon there is a definite change in the appearance of the flame. The length of the flame gradually drops and it seems to fan out. . . .

"After the blower has made the decision that the blow should be terminated, the vessel is turned down and the blast turned off."

Dust and Fume Emissions from the Bessemer Converter

In the operation of the ordinary Bessemer converter two kinds of particulate matter are discharged to the atmosphere. Pellets of metal and slag are mechanically ejected due to the violence of the air blast bubbling through the molten metal. These are known as spittings composed, as they are, of relatively coarse particles which tend to settle out on the premises close to the source. The other type is the visible orange-colored fume of iron oxide resulting from volatilization in the converter of some of the iron and its subsequent oxidation in the open air. These particles are suspended in the hot gases which, because of their buoyancy rise to great heights transporting the visible fume with them.

If these tendencies were absolute there would be no air pollution problem outside the plant area (except where the converters were located immediately adjacent to places of residence near the plant boundary), because of the limited distance travel of coarse spittings on the one hand, and on the other hand, the buoyant transport of the visible fumes to such heights as to avoid contamination at ground level.

Departure from these absolute tendencies doubtless occurs in that some smaller droplets of metal and slag, small enough to be transported upwardly in the buoyant cloud of visible fume but large enough to settle out of the cloud later by gravity, may be generated. To what extent this is a significant contributor to dustfall at different distances from a converter plant is not known. It is quite certain, however, that the visible fume portion of the emission cannot cause soiling of property at ground level when soaring away at high altitudes.

In spite of these uncertainties covering the magnitude of the air pollution potential of the converter at a distance, the problem of fume suppression has received considerable attention. The

difficulties are well summarized by Trinks[3]:

"....The gases which leave the Bessemer converter have a temperature of about 3000°F, and they are still burning after they have left the mouth of the converter vessel. These flaming gases are not confined and cannot be confined, for several reasons. The mouth of the converter is not stationary during the blow. The vessel is tilted from horizontal to vertical position at the beginning of the blow, and is laid down again before the end of the blow. And that is not all. During the main part of the blow, the position of the converter is not always the same. The blowers have a surprisingly keen ability to locate thin spots in the bottom. They tilt the vessel in such a manner that the depth of iron or steel is greater over the thin spot than elsewhere.

"Additional features exist which make any dust-catching device near the converter mouth an impossibility. A crane-way must be provided over the converter for transporting ladles which contain up to 50 tons of iron or steel. Converter vessels are removed for relining, and repair jobs must be done.

"Last, not least, the converter spits pellets of iron and steel. The yield of a converter is commonly considered to be in the neighborhood of 88 %. For every 100 pounds charged into the vessel, about four pounds of carbon burn to CO in the converter and to CO_2 after leaving the vessel. Eight pounds are thrown out as pellets or as metallic oxides. The pellets are troublesome, because they are shot out with high velocity. Some rise to a height of 50 or even 60 feet. When impinging upon a solid object such as a wall or girder, or roof, the pellets flatten and stick. The action is very similar to that of the metal-spray. In time, heavy masses of iron and steel are formed. Unless removed at regular intervals, they drop off and endanger those who are working below.

"The combination of all of these facts makes the problem of dedusting the Bessemer converter an extremely difficult one. The most obvious, but very expensive solution consists in total enclosure, with a roof at least 70 feet above ground level. At that height very few pellets can stick to the roof. The fan which draws the gases from the converter chamber must suck in enough volume of cold air to reduce the temperature of the gases to about 800°F, in order to prevent scaling. The diluting air may be drawn in from outside for instance through louvres. The cooled gases can be sent into cyclone cleaners or other known dust-separators.

"The gases which have passed through dry separators are not entirely free from smoke. The hot gases contain fumes which solidify upon being cooled in the open. If that portion of the total smoke is likewise to be eliminated, the gases must be sent through a spray tower and then through an electrostatic precipitator. The cooling water removes some of the dust and must, according to the latest laws, be filtered, before it is allowed to re-enter the river or the lake.

"A complete total-enclosure installation for several converters runs into fabulous sums. So far as the author knows, complete enclosure for the purpose of dust elimination has never been attempted in a steel plant....

"Complete enclosure was observed by the author in Germany, where it had been installed as a war measure for the purpose of blacking out the light which converters emit. Much of the converter dust was deposited in the flame tower and was removed at regular intervals through a door in the funnel-shaped bottom. Only a light brown haze was visible at the top of the tower....

"The rate of discharge of dust from a converter is not constant during the period of the blow. The thinner the bath, the greater is the rate of dust production, presumably because the metal is more thoroughly atomized and, for that reason, offers a greater surface to the air stream....

"Thin baths are found at different times, for instance, while the vessel is righted and while it is being laid down. During both periods, the blast is on, so as to keep the iron or steel from running down through the tuyeres. In a partly tilted vessel, the edge of the bath is very thin. In consequence, very thick and heavy brown smoke is emitted while the vessel is being tilted up or down. The shorter the time of tilting, the shorter is the period of producing heavy smoke....

"The greatest smoke producer in the operation of a converter is the so-called 'green bottom.' After a certain number of blows (never more than 20) the bottom has been worn thin and uneven. The blower decides, when it is time to change bottoms. The so-called green bottom is actually not green. It has been thoroughly baked. The green part comes in from the fact that the edge or rim of the bottom is smeared with clay and graphite. The new bottom is pushed up against the lower end of the vessel and is quickly fastened by swinging bolts and wedges. A charge is then run into the vessel. However, the new charge is only about 35% of the weight of a regular charge, which means that the bath is thin. If the light charge is blown for three or four minutes with full pressure, extremely dense and heavy smoke is discharged. The extreme heat of this blow dries the luting between bottom and vessel quickly. If a leak should occur, the loss would be comparatively small. If no leak is discovered during the short blow, the vessel is filled to the regular weight of charge and the blow is finished...."

Fume Control Investigations by U. S. Steel Industry

In 1952 (?) the steel companies in the Pittsburgh area sponsored studies on fume control issuing from Bessemer converters. The findings[4] confirmed the engineering complexity of the problem and produced also some interesting data. The experimental assembly included a steel framework erected in the space above an operating Bessemer converter which permitted mounting of steel plates for experiments with air jet and water spray systems to see if such arrangements would prevent the accumulation of spittings on the steel surface. These spittings, as observed by Trinks, consist of small globules of molten iron and slag which are discharged through the converter nozzles at high velocity and on impingement adhere strongly to steel surfaces until the accumulation of a thick mass heavy enough to drop off spontaneously. This condition has always complicated consideration of enclosures for confinement of the converter effluents prior to removal from the gas stream.

These experiments were conducted at a height of 55 ft above the converter mouth and included attempts to prevent accumulation of spittings by the sweep of air jets from high pressure nozzles tangential to the steel surface. All these attempts were unsuccessful.

The application of water sprays to the steel surface was successful in preventing such accumulations so long as the surface was maintained wet at all times during the exposure.

Measurement of air velocities and of temperatures in the plume at a distance of 55 ft from the converter mouth indicated that the total flow of flue gas (including the air which had become turbulently entrained in the 55-ft distance) amounted to 250,000 to 300,000 cu ft a minute at temperatures between 450 and 550°F. These values are of the same order of magnitude as those indicated from German studies cited later on.

Another experiment in which a curving steel plate was mounted 80 feet above the converter mouth also accumulated spittings in spite of the play of high pressure air jets against the surface.

Some experimental studies on dust collectors were also carried out. A 1200-cfm portion of hot dust-laden

gases from the main stream was aspirated through a small-diameter cyclone. The cyclone efficiency ranged from 66 to 76%. The effluent in the cyclone was markedly different in appearance from the main cloud. It appeared as a very light gray emission; the brown fume apparently disappeared. In one worst condition, the cyclone effluent was a light tan color. Some electric precipitator studies on a 400-cfm portion of gases showed the expected high efficiency.

Current Investigations

The importance of the Bessemer converter in the melting of special types of steel and a recognition of the desirability of finding means for fume control has led to the sponsorship by the American Iron and Steel Institute of a program at Battelle Memorial Institute. This project, just getting under way at the time of this writing, will seek by studies on a laboratory model of a Bessemer converter to determine the cause of fume formation and, hopefully, means for its prevention.

German Research

The American steel industry in addition to its own investigations has been following with keen interest experimental developments in Germany where the Bessemer converter plays an even more vital role in the refining of pig iron to steel than in this country. Because of this fact and also because the increased use of oxygen to accelerate the refining process results in even denser clouds of brown fume, the German industry has in recent years conducted some experimental work toward the suppression and removal of particulate matter.

In some German plants the converter flue gases are discharged into a chimney of very large cross-sectional area and of varying height (an arrangement instituted in World War II for protection for aircraft). This has facilitated certain experimental observations on dust collection.

Data on experiments reported by Dehne[9] supplement usefully information available from American practice. He reports on experiments on a 30-ton converter. Dust measurements indicated an average emission of solids of 132 lb/min or 1320 lb/melt is indicated. These weight figures include all very coarse material, a measured proportion of which would settle out rapidly on the premises immediately surrounding the installation. This is illustrated by the particle size data reported by Dehne whereby it is shown that about three-fourths of the particulate matter by weight is larger than 100 microns.

These facts regarding particle size are related to an installation described by Dehne known as the Bamag chimney which consists of water cooled steel plate chimney walls, rounded cross section, with cyclone dust collectors disposed around the periphery at the top. This dust collection arrangement was reported to remove 500 lb of dust per melt which in relation to the total dust quantity, 1320 lb/melt, indicates a collection efficiency of 42%.

Further along these lines he reports on the results of experiments in which well atomized water was sprayed into the chimney space and was found to remove up to 1540 lb of dust per melt with a water consumption rate of 800 to 1000 gpm. The physical conditions, however, accompanying such use of water, e.g., escape of a mud spray and accumulations of water at the base of the chimney and at points close to the converter mouth, were found to be intolerable.

The results are interesting in the indication that on a weight basis collection efficiencies approached 100 %. At the same time the visual impression of particulate removal which pertains to the very fine particulate matter was not significantly improved. In this connection Dehne offers some observations of fundamental importance in relation to this problem, as follows:

"Therefore one's visual impression of the smoke cloud which is still strikingly brown even at lowest dust concentrations by weight is not an absolutely perfect scale for measuring the efficiency of dust removal. But if the acceptability of the smoke emission is to be judged by its color, then it must be cleaned to at least 0.035 gr/ft^3. Such a criterion . . .eliminates from consideration all those dust-removing processes feasible from a cost standpoint but whose limits of efficiency would result in outlet concentrations far above the said figure."

Certainly it can be observed as a comment on these observations that there can be serious question as to the necessity for removal of all of the almost weightless fine particulate matter.

Dehne cites other experimental work involving use of water scrubbing, some of which were "more or less satisfactory but no complete success was achieved."

He shows in some detail an arrangement in which the greatest success was realized, in terms of coarse dust removal, involving the use of a short conical flue inside which water was atomized, the assembly being anchored to the converter with an open space between the converter mouth and entrance to the cones of about 13 ft. In this arrangement the high velocity gases issuing from the mouth of the converter caused the gases and their load of particulate matter to pass right through the cone and water spray. This arrangement in combination with supplementary water sprays downstream from the cone unit and with mist eliminators, resulted in a dust collection efficiency superior to the Bamag-chimney cyclone combination and had the advantage of lower cost.

Various other experimental studies were conducted on a pilot scale (7000 cfm) involving several other types of scrubbers, cloth filters, packed towers, and injection of steam into the issuing stream of gases. Their experiments also included exploration of audible sound energy in an 1800-cfm pilot plant. They were able to coagulate the fumes but the flocs disintegrated in passage through a cyclone and were not effectively caught.

Electrical precipitation was also the subject of trial on a pilot scale (7000 cfm) and the results even on a visual basis were appraised as satisfactory. However, he observes that while this apparatus performed well, it has not received as serious attention "because one could not get accustomed to the idea of having to build an electrostatic filter or precipitator of the size of the steel mill bay." This concern is entirely understandable from an inspection of the drawing illustrating the size of the gas-cleaning unit that would be required in comparison with the size of the converter itself.

In all their experiments, the efficiency of fine particulate removal was seriously reduced during the final blowing period following decarburizing, which is that period when phosphorus is removed—i.e., dephosphorizing. This smelting stage is a characteristic of European practice due to the high phosphorus content of their ores. It is not characteristic of American practice. For this stage of operations they devoted experimental effort to noting the effect of adding steam to the blast (22 lb of water per ton of pig iron). This resulted in a white waste-gas streamer, eliminating the dark-brown smoke clouds otherwise present. In addition to this advantage it was noted that clouds of smoke were no longer blown into the plant shed when the converter was tilted, a feature which is lacking in all dust-removing methods. The disadvantage was in the reduction of melting capacity—two tons per melt—i.e., from 30 tons to 28 tons or a six percent reduction.

In his final discussion pertaining to problems incident to the application of the electric precipitator which from a visual standpoint alone was superior to all methods, Dehne considers those aspects dealing with dilution of con-

verter gases with air induced into the base of the chimney enclosure in relation to gas temperature. It would be absolutely essential to eliminate major infiltration of dilution air as occurs in their present installations and to cool the gases by other means. As to the latter he lays great stress on a waste heat boiler and concludes that it may then be possible to reduce the volume of gas flowing to the precipitator to a value of 212,000 cfm. This is the figure on which the dimensions of the enormous installation shown in a drawing accompanying his paper are based. He notes also in this connection that means would have to be provided for coarse dust removal as, for example, by the Bamag round chimney, and that the chimney walls must be protected by cooling means discussed in his article.

Role of the Bessemer Converter in Steel-Making

Although use of the Bessemer converter has steadily declined relative to the open hearth furnace during the first half of the present century, it continues to serve an important role, partly for the special quality of steel it can produce and partly for economic reasons peculiar to particular plants. Some of the economic considerations are explained in the following:[9]

"The early use of converter steel in this country involved a considerable quantity of rail steel, and for many years this process was the principal method used for the production of steel . . . The rated converter capacity of the nation is approximately 12,000,000 tons of steel (1950) with a considerably greater potential capacity. Over half of this capacity represents blown metal for use in the open hearth or duplex process and the remainder Bessemer ingots. Although most of the steel in this country is manufactured by the open-hearth process, during the past few years many new converters have been installed and extensive experimental work on converter steel is in progress. The inherent advantages of the process involve economic considerations in times of peace and national security in times of war . . . .

"The cost of building a Bessemer plant is appreciably less compared with an open-hearth plant of equivalent capacity and the difference in cost depends, to some extent, upon the size of individual units. However, in the operation of a Bessemer plant, greater blast-furnace capacity is required as only a small amount of scrap is used in the process. Therefore, the investment in blast-furnace facilities for a Bessemer plant would be greater compared to an open-hearth plant and must be considered as part of the investment costs. This probably was a factor which, to some extent, was responsible for the shift from Bessemer to open-hearth production during the years between about 1910 and 1948.

"With proper facilities in an integrated plant, consisting of Bessemer converters and tilting or stationary open-hearth furnaces, the cost of producing Bessemer ingots over a period of years should be less than open-hearth ingots. When a shortage of scrap exists and the price is high, Bessemer facilities not only have an economic advantage, but are in a better position to meet market demands for steel products. This latter feature is of considerable importance in time of a national emergency . . . .

"The ratio of Bessemer to open-hearth production is influenced by the availability of steel scrap. The Bessemer process uses about 10% scrap. The duplex open-hearth process utilizes very little scrap while the stationary open-hearth process ordinarily employs 35% to 60%. Although the quantity of scrap used in the Bessemer process is small, this quantity may be increased appreciably in the future to approximately 25% by oxygen-enrichment of the blast. Further, the use of scrap in the blast furnace may be considered in the Bessemer situation.

"The Bessemer process is more than self-sufficient in scrap. The crop ends in the blooming mill alone produce about 15%, and additional scrap is produced in further processing of the material. The stationary open-hearth process produces a similar amount of scrap, but constantly uses more than it produces. The deficit is supplied by scrap originating from the Bessemer process and from sources outside the plant.

"The Bessemer process has certain economic advantages when scrap is scarce and costly, but there are periods in our economy when scrap is plentiful and cheap. Therefore, the economic pressure which exists over a period of years will be a controlling factor which influences the Bessemer steelmaking capacity of the nation . . . .

". . . Present trends in the use of oxygen and compressed air in the bath of open-hearth furnaces indicate clearly the future possibilities of a more widespread use of the basic principles of the pneumatic converter process."

Top-Blown Oxygen Converters

A smelting process that is superficially similar to the Bessemer converter is the top-blown oxygen converter or the basic oxygen furnace; it is also known by the term Linz-Donawitz, the latter deriving from the names of two Austrian towns where the early development work occurred.

The converter vessel in this process is similar to a Bessemer converter although considerably larger than most of them. A principal difference is in the means for the supply of oxygen to the molten metal. Instead of bubbling air under pressure upward through the bath, a stream of oxygen is supplied through a water-cooled pipe extending from an overhead position downward into the converter, the end being positioned at some distance above the surface of the bath. The high velocity of the oxygen results in impingement on the liquid metal surface which results in violet agitation and intimate mixing of the oxygen with the molten pig iron. Rapid oxidation of the dissolved carbon and silicon (and also of some of the iron) ensues.

Results of O_2 Concentration

The high concentration of oxygen results in the evolution of iron oxide fumes in considerably greater quantities than from the bottom-blown Bessemer converter and in a correspondingly more objectionable emission.

This problem was recognized in the initial consideration by American steel manufacturers who first considered adoption of the process and equipment for fume control was always a prime consideration in the design of the plant. As a result, the three plants now in operation on the North American continent are all equipped with effective dust-suppression equipment. One of these employs a Venturi scrubber, another one a disintegrator of the type that has long been applied to the cleaning of blast furnace gases, and the most recent one, with a Cottrell precipitator.

Control Problem Big

The latter installation illustrates the magnitude of the fume control problem and of the equipment for the purpose. A huge water-jacketed steel hood mounted above the mouth of the converter when in its normal vertical operating position, receives the fume-laden gases from the converter and also a much greater volume of room air drawn in to effect dilution of the hot gases. The stream totalling 250,000 cfm passes from the hood into a large settling chamber where large volumes of water are sprayed into it to effect cooling and also incidental removal of some of the particulate matter. The gases then pass through a flue to the Cottrell electric precipitator which removes the solids at a rate of more than one ton per hour at efficiencies of over 98%.

The dust collection system which in its physical dimensions dwarfs that of the converter proper represent more than 10% of the total plant investment.

Section V—Sintering plants

Sintering machines are those devices designed to convert fine iron ore, dust, and the like into lump form more suitable for charging into blast furnaces, by burning a mixture of this material with finely divided coke as air for combustion is drawn through a flat porous bed of the mixture. The resulting high temperatures induce a condition of incipient infusion of the iron ore particles comprising the bed and results in formation of a firm porous mass.

The bed is formed on a slow-moving grate composed of receptacle elements having perforated bottoms, known as pallets. The assembly of such pallets end to end in a hinged or linking arrangement comprises an endless metal belt with large sprockets at either end.

Just after the charge has been placed to form the bed, the coke in the mixture is ignited by the play of flames on the surface and a movement of air induced downward through the porous bed under the influence of the sintering machine exhaust fans connected to enclosures (wind boxes) underneath the top section of the endless linked pallet assembly. Thus combustion is maintained in a layer which slowly progresses downward and is completed before any given portion of the bed arrives at the end of the machine. At the end of the travel, the red hot sintered mass breaks off as the pallet elements turn downward around the tail sprocket. The hot mass of sinter is then passed to a cooler in which its temperature is reduced as cool air is drawn through it, frequently supplemented by water sprays.

There are two principal sources of dust in the operation of this process. One is in the combustion flue gases which contain some dust that has been mechanically entrained from the bed itself due to passage of air through the bed of material; it may also contain some fume due to volatilization of some of the constituents of the iron ore or dust in the mixture.

The quantity of solids in flue gases varies with type of ore and sintering machine design characteristics; the median is probably of the same order of magnitude as that issuing from a single open hearth furnace of average capacity. In the older plants no flue gas cleaning equipment was customarily included but all of the more recently constructed units are equipped with either mechanical dust collectors, scrubbers, or electrical precipitators.

The dust incident to crushing and screening operations of the resulting sinter is comparable to that resulting from any such operations characteristic of numerous other industries, e.g., rock crushing, although the quantity of dust is a small fraction of that encountered in some of these other industries. The crushing and classifying operations in the older plants are simple and few, and often not equipped with effective dust control systems. In the typical case where such plants were located well within the boundaries of a steel mill, it is probable that the resulting dust is more of a nuisance to adjoining departments of the steel plant than to the surrounding community.

In the newer plants, however, well designed exhaust systems in which hoods and exhausted enclosures are provided around crushing equipment, screens, and transfer points in the material handling system, are universally employed. High efficiency cyclones are commonly employed for dust removal and are effective in the removal of coarse particles which might otherwise be responsible for a local nuisance.

The first sintering machine in this country was installed in 1911 and such machines became increasingly a common item of equipment in years following although on a small scale in terms of later developments. They were primarily applied to the iron ore dust that blew out of blast furnaces into the flues and other gas passages. Stockpile accumulations of this dust represented an increasing nuisance until the sintering process was developed which transformed the material to lump form which would be recharged to the blast furnace, profitably.

The role of sintering machines in steel plant operations assumed a new stature following World War II. This was due to the changing character of iron ore supplies when, with the approaching exhaustion of the high grade lumpy ores of the Messabi ore deposits, new sources became available which had high properties of iron ore fines. This circumstance was accompanied by increasing evidence that any important reduction in the fines supplied to blast furnaces not only increased production but also reduced material costs due to decreased requirements for coke and limestone. As a result of these developments, sintering machines are being installed on a large scale in all segments of the steel industry. It is reported (Packard) that the sintering capacity of the steel industry in this country had attained a level of 60,000 tons per day at the end of 1958, a striking increase over the figure of 10,000 tons in 1939.

These economic developments respecting the distribution characteristics of ore charged to blast furnaces practically insure that the older, inefficiently designed sintering plants will be replaced by modern ones in coming years. This process is already taking place at the time of this writing.

Modern sintering plants have capacities ranging from 2000 to more than 6000 tons of sinter per day. The dimensions of one of the latter capacity are interesting. Having a bed width of 12 ft, it extends to a length of about 150 ft. Exhaust fans draw air through the bed of such a unit at a rate of more than 500,000 cfm measured at temperatures of 350°F. This is the flue gas volume which is subject to gas cleaning for removal of dust or fume.

The exhaust system for control of dust incident to crushing and screening of the finished sinter involves air flows in the vicinity of 150,000 cfm.

The fact that all new sintering plants are being provided with equipment for control of air pollution in combination with that respecting the high rate of obsolescence of the older ones constitutes firm assurance that this type of equipment is quite unlikely to be a source of future dissatisfaction.

Section VI—Electric Furnaces

The electric arc furnace for the making of steel, first employed in this country in 1906, has undergone marked development during the past 20 years. In 1935 it accounted for 1.3% of the total steel-making capacity of ingot-producing plants in the country and by 1954 the proportion had increased to 8.4%. The remaining capacity is accounted for in that of open hearth furnaces and Bessemer converters. The use of electric furnaces in steel foundries has also developed at a rapid rate during the same period, but the present discussion is largely confined to the integrated steel plants having also open hearth furnaces or pneumatic converters or both.

Role of Electric Furnaces

The function of electric furnaces is in general much more specialized than that of open hearth furnaces and pneumatic converters, in that they are especially adapted to and are primarily used for the production of special alloy steels.

". . . the electric-furnace products represent practically all of the stainless, constructional alloy, tool, and special

alloy steels used in the chemical, automotive, aviation, machine-tool, transportation, food processing, and many other important industries. While at the present time the electric-arc furnace cannot compete with the larger open-hearth furnace as to cost in the production of the commoner grades of steel, yet the electric furnace, if operated in a favorable scrap-producing area with favorable power rates, in many cases can produce ordinary carbon steels at costs comparable, and sometimes less than, open hearth costs."[10]

The furnaces in operation today for the manufacture of steel consist essentially of refractory-lined cylindrical vessels through the roof of which large carbon electrodes pass downward into the charge. The three electrodes supplying current at rates as high as 10,000 to 20,000 amperes generate great quantities of heat as the current arcs from one electrode to the bath, passes through the bath and arcs to one of the other electrodes. Since World War II many electric furnaces having a capacity of 10 tons of steel and with shells 20 ft in diameter have been placed in operation. Within the past few years, furnaces of 200 tons capacity with shells approaching 30 ft in diameter have been installed.

Electric furnaces are completely housed in mill buildings and therefore, unlike open hearth and Bessemer converter installations, the passer-by does not see the equipment or evidence of its operation other than in the appearance of brownish smoke issuing into the open atmosphere through roof ventilators of the buildings housing them.

Fume and Dust Emissions

The high temperature inside the furnace created a natural draft which induces a flow of air inward through spaces around charging doors and outward through the annular spaces in the roof surrounding the three electrodes, carrying with it variable quantities of fume and dust which are discharged into the atmosphere of the mill building housing the furnace. It escapes subsequently to the open atmosphere through openings provided by the roof ventilators.

During the melt-down stage, oxidizing conditions prevail and reactions occur that are similar to those in the bath of the basic open hearth furnace Although the differing characteristics of the two processes indicate differences in the mechanism of fume generation they are not altogether dissimilar. Heat is applied to the charge in the electric furnace at a much higher rate per unit area of surface and therefore conditions are favorable for oxidation and volatilization of metal. A similar condition prevails in the open hearth process although the dimensions respecting heat transfer and contact with oxygen are altogether different. In both processes a so-called boil occurs from escape of carbon monoxide resulting from reactions between carbon and iron oxide. Oxygen gas introduced to the bath through a pipe or lance is applicable to the electric furnace process as well as to the open hearth and the resulting metal oxide fumes, of course, have the same origin.

The quantity of escaping dust and fume has been variously estimated to range from five to 30 pounds per ton of steel melted, depending on size of furnace, and the character of scrap as to its content of fine dirt.

The magnitude of the resulting dust and fume emissions inside the mill building, especially to cranemen, is therefore roughly proportional to the size and number of the furnaces. As larger and larger furnaces have been developed and more of them installed in one building, the emissions have become intensified not only inside the building but in the immediate neighborhood, and extensive engineering efforts have been applied to the control of such fume during the past several years.

The Fume Control Problem

The characteristic distinguishing this problem of dust and fume control from other metallurgical furnaces has to do mainly with the development of means for channeling the stream of dust- and fume-laden gases through a flue leading to gas cleaning equipment without interference with proper function of the furnace. In this respect the problem is roughly analogous to that of the Bessemer furnace in that capture and transport of the fume-laden gas and air stream is the primary problem; after that point, treatment for removal of particulate matter in more or less conventional kinds of equipment can be considered.

Furnace Hoods

The first devices for fume control that were quite successfully applied to the small acid-lined furnaces of the steel casting industry consisted in steel enclosures mounted on the furnace roof which were connected to exhaust systems through suitably designed flexible linkages, e.g., swivel elbows, telescoping joints, and the like. An opening is provided in the central portion of the exhaust enclosure for free passage of the electrodes, and sections overhanging the roof above charging doors serve to withdraw fume-laden leakage air from those locations into the exhausted enclosures. For mechanical reasons, the application of such a method for exhausting electric furnace fumes has been limited to furnaces of smaller sizes.

Interior Exhaust

In a move toward simplification of the mechanics of fume exhaust, some installations have been made in recent years whereby fume is withdrawn directly from the interior of the furnace through a hole in the roof while carefully controlling the rate of exhaust in relation to the internal negative pressure so as not to chill the interior of the furnace and its charge and to avoid exposing the steel to excessively oxidising conditions.

This system can effect control of the fume emission at rates of air and gas exhaust much lower than in the roof top hood system previously mentioned although the gas temperatures issuing from the furnace are very much higher (2000–2500°F); this necessitates refractory-lined flues to the point where such gases enter the gas cooling unit.

Limitations of Direct Exhaust Method

The principal limitations of this system are related to metallurgical considerations. One of the particular advantages of electric furnaces in the refining of alloy steels is in the facility with which the oxidizing or reducing character of the slag can be controlled, and in the reducing furnace atmosphere that results from the non-oxidizing character of the electric heat source. Because of this circumstance high proportions of oxidizable metal elements in the making of high alloy steels can be melted with a minimum of loss from oxidation.

It has been felt in the industry that a system which controls escape of furnace fumes by inducing a flow of air into the furnace interior would make it difficult or impossible to maintain the essential reducing character of the slag in the later stages of two-slag (oxidizing and refining) process employed in the making of high alloy steel.

Recognizing that this opinion is based on inference rather than on actual experience, an experimental study was launched in 1958 by the Subcommittee on Electric Furnaces of Allegheny County, Pa. Their plan involves full-scale installation on an industrial electric furnace of a "water-cooled, hole-through-roof, emissions off-take which will be connected to a cooling system, fan, and stack. The purpose of the experiment is to determine what effect negative furnace pressure will have on the melting of certain alloy and stainless steels which require double slag practice . . . to determine whether its installation will interfere with furnace operation and production in any way . . . maintained in the production of alloy and

stainless steels where the 'two-slag' process is employed."[11]

It is probable that a definitive report on these studies will be issued by this group by June, 1959.

The present status and future prospects for electric furnace fume control is well summarized in the same report:

"... a general conclusion is that emission from electric furnaces to the atmosphere can be reduced.

"The problems are not ones for which simple solutions can be found. This applies especially to installations already made where buildings and furnaces were installed without planning emission control, and where vertical and horizontal space may not allow a practical installation of control equipment.

"Also, it will apparently be necessary to study each furnace or furnace group separately when considering an installation, since there will be different charges to and products from each one, different methods of fluxing, lancing, and operating ....

"Obviously the economics of each installation needs careful study, from the viewpoint of investment, operation, and repair of the control system, as well as to how its operation affects output and quality of product from the furnace. In some installations, an economic study may necessarily consider whether to abandon the present furnaces and build new ones on which controls may be more advantageously placed."

Section VII—Miscellaneous Processes

Besides the dust, smoke, and fume control problems treated in the earlier sections of this report, there are a number of miscellaneous operations which logically should be included in such a report as this, although their individual significance as sources of air pollution is relatively minor in comparison with some of those discussed previously.

Scarfing Machines

During the past 40 years, as the technology of steel fabrication developed requirements for still higher qualities, ever increasing attention has been devoted in one particular to the conditioning of semi-finished products. A major element in this area involves the need for removing surface defects of blooms, billets, and slabs prior to shaping, as by rolling, into a product for the market. Such defects as rolled seams, light scabs, checks, etc., terms describing imperfections like surface fissures, scabs that are inhomogeneous with respect to the main body of the metal piece, will generally retain their identity (although not shape) during subsequent forming processes and result in products of inferior quality.

In the earliest days of the development, pneumatic chisels were employed to remove such surface defects. About 25 to 30 years ago the scarfing process developed and today represents an important operation in the making of high grade steel products. It consists essentially in supplying streams of oxygen as jets to the surface of the steel product under treatment while maintaining high surface temperatues that result in rapid oxidation and localized melting of a thin layer of the metal. Originally the process was a manual one consisting in the continuous motion of an oxyacetylene torch along the length of the piece undergoing treatment. In recent years the so-called hot scarfing machine has come into wide use. This is a production machine adapted to remove a thin layer ($\frac{1}{8}$-in. thick or less) of metal from all four sides of red hot steel billets, blooms, or slabs as they travel through the machine in a manner analogous to the motion through rolling mills.

The process results in simultaneous generation of quantities of both dust and fume of such magnitude as to be quite intolerable inside the mill building. Such installations therefore are equipped with exhaust systems designed to remove this material at its source and to deliver the contaminated air stream to a dust collector before discharge to the atmosphere.

The exhaust system design is conventionally based upon the exhausting of 750 to 1500 cfm of air per scarfing nozzle and for machines now in common use, this results in exhaust systems ranging from 20,000 to 100,000 cfm.

The scarfing process involves the use of water jets adjacent to the oxyacetylene torches and the steam to be generated is drawn off along with the fume and dust.

The scarfing process will typically remove two to three percent of the total metal but most of this material is in the form of coarse particles not fine enough to be categorized as dust. The fine material entrained in the air stream of the exhaust system will amount to approximately 36 grains per pound of metal removed and in typically heavy duty scarfing operations, this may amount to 50 to 75 lb of solids per hour.

The bulk of the particulate matter on a weight basis is represented by the non-fume fraction and various types of wet scrubbers as well as electrical precipitators have been successfully applied to the efficient removal of the entrained dust, although a visible plume due to the escape of very fine particulate matter will be noticeable as an emission from the stack. This material, however, represents only a few pounds per hour and has little or no tendency to settle out of the atmosphere and thus to contribute to dustfall nuisance.

Heating and Reheating Furnaces

The emission of smoke due to inefficient combustion of fuel (blast furnace gas, coke oven gas, natural gas, fuel oil and pitch, or tar from the coke oven by-product plant) represents another area of potential air pollution, although of diminishing significance. There are numerous operations throughout the steel plant involving the heating and re-heating of ingots, blooms, and billets in connection with the operation of the rolling mills and other finishing processes.

In the earlier days of the industry when the technology of furnace design was less well understood, there were frequent instances of smoking chimneys due to lack of automatic fuel-air ratio controls and to insufficient combustion space with the result that the fuel gases were incompletely consumed before coming in contact with the relatively cold steel, and black smoke resulted. With the almost universal use of instruments and automatic combustion controls, modern furnace designs avoid this error and one rarely sees the emission of black smoke from them. Some of the older heating and re-heating furnaces of poor design are still in operation but are rapidly becoming obsolete and being replaced with modern units, and it can therefore be concluded that such few smoking chimneys as remain in the steel industry will disappear before long.

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(*Continued on page 253*)

An OBJECTIVE METHOD for Site EVALUATION*†

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The primary factors in a realistic evaluation of a site are ones not directly related to air pollution. These can be broadly classified as economic, administrative, and political. Once these factors have been considered and a proposed site (and at times sites) is acceptable, then the technical problems related to air pollution are brought under consideration. The problem considered in this paper is the development of an objective rating system based on a mathematical model that only considers the important technical aspects. Actually if the nontechnical problems could be expressed mathematically, the entire problem would be treated objectively, because since the advent of high-speed computers, mathematical models can be solved that will treat the entire problem as a whole rather than considering each factor separately and then having a subjective decision made as is done at present.

Technical Problems Related to Air Pollution

The first factor that must be considered is the distribution of pollution at the site. Once the pollutant of interest is established, basic output estimates can be made either theoretically or experimentally to predict the amount of pollutant that will reach the atmosphere from a plant. Then the meteorologist computes the concentration for all necessary points in space by means of appropriate diffusion equations for the area and for the particular source in question. These results may be modified by the aerodynamics of the system. This effect can either be natural, such as terrain configurations, or man-made, such as the effect of the plant itself or other obstructions on the distribution of the pollutant. At times, the aerodynamics of the system can be checked in a wind tunnel when the scale is appropriate. If not, further verification must be derived from experimental evidence. The measurement of concentration in the field may be, if desired, the final evidence describing the distribution of the pollutant.

The distribution of the receptors sensitive to the pollutant must be obtained. The word receptor is used because in many pollution problems the effect may be on an inanimate object. The distribution can be obtained directly by means of a census or survey of the actual distribution of receptors around the site, or indirectly by means of statistical correlation. For example, the number of people in an area can be predicted to a high degree of precision by counting the number of electrical meters.

The final technical problem to be considered is the reaction of the receptors to the pollutant. This again can be done in a laboratory such as was recently done on the effect of eye irritation as a function of irradiation intensity.[1] However, under certain circumstances where it is not feasible to perform a laboratory experiment on the receptor, it is possible from previous experience to formulate quite accurately the theoretical reaction of the receptor to the pollutant.

Treatment of Data

All the technical aspects mentioned in the previous section can usually be calculated to an acceptable degree of accuracy. The distribution of pollution by means of the diffusion equations can be predicted to several parts per million and accurately verified with instrumentation of equivalent precision. Similarly, the distribution of the receptors can be predicted, and in most cases, the reaction of the receptors to the pollutant can be specified to a higher degree of precision than needed. However, in a practical problem, there is no attempt to combine these three important factors quantitatively. Normally they are treated separately and are only considered together on an extremely qualitative basis. In a typical case, management is likely to decide, quite subjectively, that one site is better or worse than another because, "Concentrations at plant A will reach 2 ppm more often than at plant B, and there are more sensitive areas at the A site, etc." An attempt is made, in this paper, to formulate a hypothesis that can be used as a starting point in combining the factors of importance relating to an air pollution problem and to develop a rating number that will enable administration to decide objectively upon the relative merits of sites. Similarly, this model, as will be shown, could be used as a basis for zoning regulations.

Hypothesis

Rating of a site is equal to the sum of the receptors being affected multiplied by a function relating both concentration and its effects.

In effect, this hypothesis implies that a rating must consider not only the few receptors receiving a large concentration, but also the larger number of receptors receiving a smaller concentration. The latter case may be as important and is normally neglected, as most zoning or tolerance limitations are "... below a given maximum value χ" and not inclusive of receptors.

Mathematically, this model is approximated by the following equation:

$$R = -\int_0^\infty h(C)dN(C) \qquad (1)$$

where

R = rating (the higher the number, the more unfavorable is the site for a given pollutant)
$h(C)$ = receptor response function
$N(C)$ = number of receptors being affected by a concentration C

This hypothesis, which is an extremely simple model, accounts for the three technical aspects of air pollution and indicates the true complexity of the problem as the integral parts of the equation are derived.

Evaluation of N(C)

The number of receptors being affected by a concentration C is obtained by combining the functions describing the variation of concentration and/or deposition in space with the distribution of receptors around the site.

The distribution of concentration in space from a continuous point source at

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the ground can be described by means of Sutton's[3] equation:

$$C(x, y, z) = \frac{2Q}{\pi C_y C_z u x^{2-n}} \times e^{-y^2/C_y^2 x^{2-n}} e^{-z^2/C_z^2 x^{2-n}} \quad (2)$$

where

C = concentration, gm/m^3
Q = output rate, gm/sec
C_y = horizontal diffusion parameter, m$^{n/2}$
C_z = vertical diffusion parameter, m$^{n/2}$
x = distance downwind, m
y = distance crosswind, m
z = distance vertically, m
n = index of turbulence, dimensionless
u = mean wind speed, m/sec

Since we are interested in ground level concentrations, we let $z = 0$ and equation 2 can be rearranged as:

$$\frac{y^2}{C_y^2 x^{2-n}} = \ln\left[\frac{2Q}{\pi C_y C_z u x^{2-n} C}\right] \quad (3)$$

or:

$$y = \pm C_y x^{1-(n/2)} \times \left\{\ln\left[\frac{2Q}{\pi C_y C_z u x^{2-n} C}\right]\right\}^{1/2} \quad (4)$$

The furthest distance at which a particular concentration crosses the centerline is of practical importance and is obtained from the following equation:

$$X_D = \left[\frac{2Q}{\pi C_y C_z u C}\right]^{1/1-n} \quad (5)$$

where X_D = maximum distance at which a particular concentration is found.

Thus equation (4) simplifies to:

$$y = C_y x^{1-(n/2)} \left[\ln\left(\frac{X_D}{x}\right)^{2-n}\right]^{1/2} \quad (6)$$

A generalized expression for the distribution of receptors within the field of interest around a site is assumed to be:

$$\mu = \alpha x^\gamma = dN/dxdy \quad (7)$$

μ = population density
α, γ = constants to be determined experimentally from the statistical data around site
N = number of receptors

Therefore, the number of receptors in an area $dxdy$ can be written as

$$dN = \alpha x^\gamma \, dxdy \quad (8)$$

and assumed symmetry about the y axis:

$$dN = 2y\alpha x^\gamma dx \quad (9)$$

Substituting y from equation (6) into (9) and solving the integral will allow us to obtain the number of people within the area bounded by a particular concentration:

$$dN(C) = 2\alpha x^\gamma C_y x^{1-(n/2)} \times \left[\ln\left(\frac{X_D}{x}\right)^{2-n}\right]^{1/2} dx \quad (10)$$

Integrating:

$$N(C) = 2\alpha C_y \int_0^{X_D} x^{\gamma + 1 - (n/2)} \times \left[\ln\left(\frac{X_D}{x}\right)^{2-n}\right]^{1/2} dx \quad (11)$$

Letting $x = X_D \rho$ simplifies this equation to:

$$N(C) = 2\alpha C_y \frac{2Q}{\pi C_y C_z u C}^{\frac{\gamma + 2 - (n/2)}{2-n}} \times \int_0^1 \rho^{\gamma + 1 - (n/2)} \left[\ln\left(\frac{1}{\rho}\right)^{2-n}\right]^{1/2} d\rho \quad (12)$$

Finally, we let

$\rho = e^{-t}$ and by means of a Gamma function, obtain the final form of the number of receptors being affected by concentration C

$$N(C) = \alpha C_y \pi \left[\frac{2Q}{\pi C_y C_z u C}\right]^{\frac{\gamma + 2 - (n/2)}{2-n}} \times \sqrt{2-n}[\gamma + 2 - (n/2)]^{-1/2} \quad (13)$$

which has the form:

$$N(C) = F\left(\frac{A}{C}\right)^\beta \quad (13A)$$

Evaluation of $h(C)$

The receptor response function, $h(C)$ is obtained from a plot of effect versus concentration. This function, if considered at all, is usually treated in a very qualitative manner. Actually $h(C)$ can easily be approximated to the same order of accuracy as $N(C)$. By means of theoretical or experimental evidence, a plot of response (complaints, damage, irritation, legal action, etc.) versus concentration (dose, degree of pollution, etc.) can be made and the function describing this curve is $h(C)$.

This function can have a variety of forms, some of which are plotted in Fig. 1.

In Fig. 1a the response is linear—as the concentration increases so does the response.

In Fig. 1b—a single step function—this reaction is a yes or no affair—there is no effect until a certain concentration, and then every receptor is affected.

Fig. 1c—a step function with a linear trend in between— is a combination of a and b.

Fig. 1d—a multiple step function—where the response increases in finite levels of the concentration.

All these simple functions can be used to describe $h(C)$ and then combined with $N(C)$ to obtain a rating of a site. However, to have $h(C)$ as general as possible and still retain the proper form describing most of the physical process involved, it is assumed that the receptor response function is of a log normal form, Fig. 2.

thus:

$$h(C) = \int_{-\infty}^{\log C} \frac{1}{\sqrt{2\pi}\sigma} e^{-(t - \log B)^2/2\sigma^2} \times dt \quad (14)$$

or by letting $C = e^t$

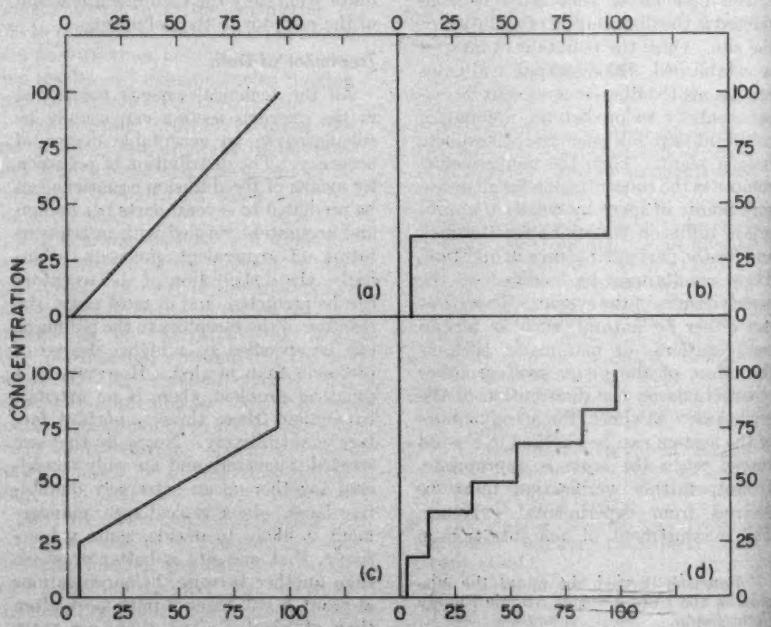

Fig. 1. Various receptor response functions.

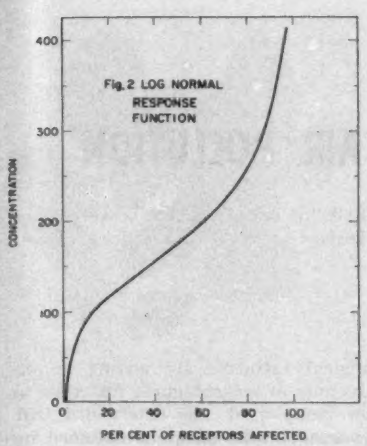

Fig. 2. Log normal response function.

$$h(C) = \int_0^C \frac{1}{\sqrt{2\pi}\sigma} e^{-(\log C - \log B)^2/2\sigma^2} \times \frac{dC}{C} \quad (14a)$$

This function has a great degree of flexibility. With the appropriate values of B and σ, equation 14 can be used to fit all the curves shown in Fig. 1. Also, it is in agreement with many human-response functions.

Evaluation of R

The rating of a site, R, is computed by combining the receptor response function, equation (14), with the number of receptors being affected, equation (13), according to the hypothesis stated by equation (1). Namely:

$$R = -\int_0^\infty h(C)dN(C) \quad (1)$$

Integrating by parts

$$R = -[h(C)N(C)] + \int_0^\infty (C)dh(C) \quad (15)$$

The first part of this equation goes to zero because $N(C) \to 0$ at 0 (no receptors at the source) and $n(C) \to 0$ at ∞ (no effect at an infinite distance from source).

Therefore

$$R = \int_0^\infty N(C)\, dh(C) \quad (15a)$$

Substituting (13a) and (14a) into this equation and letting

$$e^t = C \text{ and } e^b = B$$

$$R = FA^\beta \int_{-\infty}^{\infty} \frac{e^{-\beta t}}{\sqrt{2\pi}\,\sigma} \times e^{-(t-b)^2/2\sigma^2}\, dt \quad (16)$$

or:

$$R = FA^\beta e^{-b^2/2\sigma^2 + (b-\beta\sigma^2)^2/2\sigma^2} \times \int_0^\infty \frac{1}{\sqrt{2\pi}\sigma} e^{-[t-(b-\beta\sigma^2)]^2/2\sigma^2}\, dt \quad (17)$$

The integral is equal to unity by statistical theory. Therefore, the final equation for the rating of a site is:

$$R = \frac{\pi\alpha C_y\sqrt{2-n}}{(\gamma + 2 - (n/2)^{3/2}} \times \left(\frac{A}{B}\right)^\beta e^{\beta^2\sigma^2/2} \quad (18)$$

where

$$A = \frac{2Q}{\pi C_y C_z u} \quad \text{and} \quad \beta = \frac{\gamma + 2 - (n/2)}{2 - n}$$

Equation (18) appears to be complicated. Actually the rating of a site can easily be evaluated as is shown in the following section.

Sample Calculation

This paper was conceived from the work done in WASH 740[3] in which a study was made on the possible consequences in terms of injury to persons and damage to property if a hypothetical major accident should occur in a typical large nuclear power reactor. This study is still of current interest. Therefore, the example used will be the same as presented there. Let us consider a large nuclear power plant (500 MW) approximately 30 miles from a large city. What would its rating be in terms of a hypothetical accident from a hazard-to-people point of view?

Let us assume that this theoretical accident occurred and the highly improbable amount of 50% of the entire fission product inventory was released during typical daytime conditions. The input parameters are:

$Q = 2 \times 10^8$ curies
$n = 0.25$
$C_y = 0.40\ m^{n/2}$
$C_z = 0.40\ m^{n/2}$
$u = 5$ m/sec

The distribution of people within a circle around the site based on data obtained from five existing sites is given by

$$N = 200R^{2.53} \quad (R \text{ in miles})$$

Thus,

$$\alpha = 5.4 \times 10^{-5} \quad \text{and} \quad \gamma = 0.83$$

The constants obtained by fitting a log-normal function to the assumed human-dose response curve are:

$$B = 173 \quad \text{and} \quad = 0.473$$

Substituting all these values into the equation yields

$$R = 2.8 \times 10^4$$

If the release took place at night, the only values that would change are ones reflecting an inversion condition:

$n = 0.55$
$C_z = 0.05\ m^{n/2}$
$u = 3.0$ m/sec

The rating of the site would reflect this situation as the number increases to

$$R = 4.62 \times 10^7$$

Similarly, the rating can be computed for different sites with their appropriate population distribution for comparative purposes.

Application

Rating Scales—This rating system is an arbitrary one, and before it can directly be applied, the scales must be calibrated for various pollutants. The calibration will be based on experience and will reflect the distribution of receptors as well as the distribution of concentration.

Response Scales—The response of the receptors to the pollutant *must* be devised analytically and in an objective manner. A functional form of it can always be made theoretically or experimentally.

Receptor Scales—$N(C)$, the number of receptors being affected by a given concentration is the only part of the hypothesis that can be varied. The two previously mentioned scales are fixed for a site. However, $N(C)$ can be concontrolled by zoning in two ways:

a Limiting concentration: Concentration is limited in the existing manner of reducing the output of pollutants from sources either by increasing the efficiency of the plant (scrubbers, filters, precipitators, higher stacks, etc.) or by limiting the number of plants that are able to operate in an area to prevent the air from becoming saturated with a pollutant.

b Limiting receptors: The number of receptors being affected can be reduced by having larger controlled areas or plant sites. An extreme case is the areas where weapons are tested. There a large pollutant source can be emitted, because the area affected has no people. Another manner of controlling the receptor density around a pollutant source is by zoning laws to keep the density low around existing sources so that R will remain within proper limits.

Conclusions

An attempt has been made to combine objectively the three technical aspects related to site selection from an air pollution point of view. At present, the distribution of pollution, the distribution of receptors, and the effect of the pollutant on the receptors are considered quantitatively on an individual basis. They are then thrown into the proverbial pot, out of which arises a subjective decision. The model formulated avoids this situation and also suggests a method of zoning.

(*Continued on page 251*)

VEGETATION *Symptoms as a* MEASURE *of* AIR POLLUTION*

HERBERT C. McKEE, Manager, Industrial Pollution and Analytical Research, and
FREDERICK W. BIEBERDORF, Senior Biologist, Southwest Research Institute, San Antonio, Texas

A two year survey of air pollution conditions in the Houston, Texas area has recently been completed by Southwest Research Institute under the sponsorship of the Houston Chamber of Commerce. The survey was designed to provide information on present air pollution conditions in the Houston area, and on factors which affect air pollution. Previous publications describe the meteorological work and the chemical sampling and analysis which was performed.[1, 2]

A vegetation study was included in this survey in order to determine any economic loss and to use vegetation symptoms as a means of obtaining information on air pollution in the Houston area. A preliminary examination of all types of vegetation revealed certain symptoms which could not be attributed to drought, insects, fungi, or other natural causes. Therefore, further work was undertaken which pinpointed air pollutants as the causative agents and techniques were developed to use this information as a means of measuring relative pollution levels in different sections of Harris County, in which Houston is located.

Preliminary Survey

In the preliminary survey all species of vegetation were inspected including trees, shrubs, vegetable gardens, grasses, and weeds. With several species, a few isolated examples of symptoms due to air pollution were found, but were too infrequent to be attributed to any community-wide or area-wide effect. These were evidently due to localized situations in particular areas and did not warrant further study on an area-wide basis. However, with two species of trees, the ash and the elm, visible symptoms were found on a large percentage of the trees in the industrial district along the Houston ship channel, indicating an effect throughout a large area. Therefore, the ash and elm trees were selected for a more detailed study in order to determine the cause of the symptoms and to use the symptoms as a means of measuring relative pollution in different areas.

Figures 1 and 2 show typical specimens of ash and elm leaves collected in the areas where the visible symptoms were most evident, with normal leaves for comparison.

Cause of Symptoms

Leaves which showed visible evidence of damage were analyzed chemically in an attempt to determine the cause of the damage. Leaf samples were dried to constant weight and extracted with three portions of hot water. A small amount of nitric acid was then added to each sample to prevent the growth of bacteria and fungi, and the samples were analyzed chemically for sulfite, sulfate, chloride, and fluoride. Samples which did not contain nitric acid were also analyzed for nitrate.

Sulfite was determined by adding to the sample a solution of sodium tetrachloromercurate and a small amount of P-rosaniline hydrochloride and formaldehyde solutions. Under these conditions, sulfite reacts to form a purple color which can be determined spectrophotometrically.[3]

Sulfate was determined by adding a solution of sodium chloride and hydrochloric acid, and a small amount of barium chloride. Sulfate was determined turbidimetrically as barium sulfate.[4]

Chloride analyses were made by acidifying the samples with nitric acid and adding silver nitrate. Chloride was determined turbidimetrically as silver chloride.[5]

Fluoride was determined by distillation of samples from sulfuric acid, followed by the usual colorimetric method used in water analysis.[4]

Nitrate was determined colorimetrically with xylenol reagent.[6]

With all determinations a reagent blank is required. Since the water extracts were colored, 10 ml portions of the extract without the necessary reagents were used as blanks in the sulfite, sulfate, and chloride determinations. Distilled water in an amount equal to the volume of reagents used was added to the blanks to duplicate the dilution effects of the reagent on the color of the original extracts. By adding known amounts of reagent grade materials to the samples, it was determined that accurate results could be obtained by this procedure and that the color of the original leaf extracts did not interfere.

Since the chemical composition of leaf samples was unknown, no convenient reference point was available tc determine whether measured concentrations were abnormally high; therefore, samples were collected in areas far removed from the industrial area to use as control samples for comparison.

In the case of sulfite, chloride, fluoride, and nitrate analyses, there was no consistent pattern in the results obtained. The amounts measured varied from sample to sample among samples from the same area, and no one area showed significantly higher or lower amounts than other areas. This appeared to eliminate these three components as possible reaction products attributable to air pollution.

With the sulfate analyses, consistently high results were obtained on samples collecting near the ship channel industrial district, in the areas where visible damage was noted. This would indicate sulfur dioxide, sulfate-containing dust, or sulfuric acid mist as the causative agent.

Since at least one source of sodium sulfate dust particles was known to be present in the area, it was necessary to distinguish between soluble sulfate present as a reaction product involving sulfur dioxide, and dust-containing sodium sulfate which might be deposited on the surface of the leaves. This was accomplished by analyzing the leaf extracts for sodium by flame spectrophotometer.

With samples collected in the control area there was no consistent pattern of excess sodium over sulfate or vice versa. The amounts of both were in general quite low. With samples collected in the industrial area, amounts of both sodium and sulfate were higher but still there was no consistent ratio between sodium and sulfate. There appeared to be a completely random distribution of sodium/sulfate ratios among the samples collected and there-

* Presented at the 52nd Annual Meeting of APCA, Hotel Statler, June 21–26, 1959, Los Angeles, Calif.

Fig. 1. Leaves of Arizona Ash Tree: (a) affected by air pollutants (b) normal leaves for comparison.

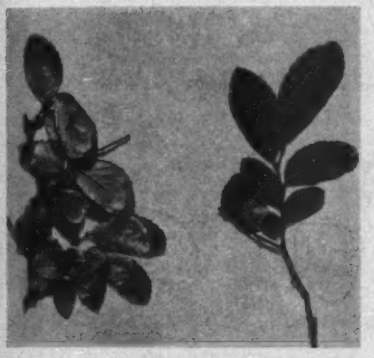

Fig. 2. Leaves of Cedar Elm Tree: (a) affected by air pollutants (b) normal leaves for comparison.

fore it was assumed that the sodium was not related to the sulfate, which eliminated sodium sulfate as a source of the high sulfate values. While it is undoubtedly true that a few of the high sulfate results obtained in the industrial area were due to sodium sulfate, it appeared that interference from this source was negligible and was not of statistical significance.

An abnormally high sulfate content would also result if the leaves had been damaged by sulfuric acid spray. However, this seemed less likely than damage due to sulfur dioxide, since the sampling and analysis work showed that sulfur dioxide was found frequently in all portions of the ship channel area, whereas traces of sulfate and sulfuric acid mist were found only infrequently.

On the basis of this evidence, sulfur dioxide was suspected as the causative agent of the observed symptoms. In order to test this possibility, ash and elm trees were sprayed with water solutions of sulfur dioxide and the sprayed areas enclosed on polyethylene tents to maintain high humidity following the spraying. Sodium sulfate and sodium carbonate were also used in water solutions since sources of these two materials were known to be present in the area.

It was found that symptoms very similar to those observed in the field were developed in these laboratory experiments with the sulfur dioxide solutions, using both 0.5 and 1.5% by weight (SO_2 reacts in water to form sulfurous acid, but concentrations were calculated on the basis of unreacted SO_2). Plants were also treated with 20% by weight of sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3). No visible damage resulted from treatment with the sodium carbonate solutions while the sodium sulfate solution caused a very slight burning of the ash. Since sulfur dioxide caused symptoms similar to those in the field in much lower concentrations than the sodium sulfate, the results again indicated very strongly that sulfur dioxide was responsible for the visible damage. This hypothesis was further supported by the atmospheric sampling data mentioned previously, which showed that sulfur dioxide was found throughout the industrial section and was the most widespread in occurrence of all pollutants measured. Furthermore, the areas in which sulfur dioxide was found most frequently corresponded to the area in which the most severe visible symptoms were found.

Rate of Accumulation

To provide some information on the way in which sulfate might accumulate in tree leaves, samples were taken periodically throughout the 1957 growing season to see if a definite pattern might be established as a function of time. For this purpose, ten elm trees and ten ash trees were selected in the ship channel area, in the sections where visible symptoms were most evident and where previous analytical results had shown the highest sulfate concentration. Leaves from these same twenty trees were collected at intervals throughout the growing season and analyzed. Each time, leaves were collected that had been on the tree since the beginning of the season; as far as possible, leaves forming a part of secondary growth were avoided.

As before, all samples were analyzed for both water-soluble sulfate and for sodium, since it was possible that sodium sulfate dust might have been deposited on the leaves. Since most of the trees were in areas adjacent to known sources of sodium sulfate, it was decided to reduce all sulfate values by an amount equivalent to one-half the sodium (on the basis of Na_2SO_4) and to assume that only the remaining sulfate was the result of exposure to sulfur dioxide. Such a procedure should be conservative; i.e., actual sulfur dioxide pollution should be somewhat greater than indicated by the corrected values. However, since the purpose of the samples taken at intervals during the growing season was to obtain relative values rather than absolute values, the exact procedure for making the correction is of only minor importance, and the same type of accumulation pattern was demonstrated if no correction was made.

Figure 3 was prepared from the resulting data, showing corrected sulfate values as a function of time. It was noted that results with individual trees showed some irregular variation time to time, due evidently to bleaching effects of rainfall or other extraneous effects. However, for the average values obtained with the same ten trees, there was a consistent pattern. In the

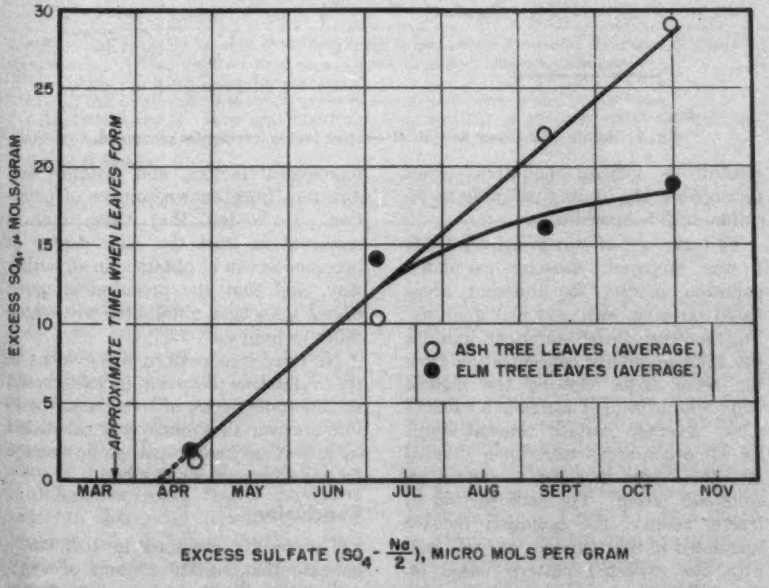

Fig. 3. Accumulation of sulfate in vegetation.

case of the ash trees, sulfate concentration increased as a straight line function throughout the growing season, tending to confirm the relationship between sulfate concentration and exposure to atmospheric pollutants, probably sulfur dioxide. In the case of the elm trees, there appeared to be a leveling off, indicating that the sulfate concentration approached a saturation point near the end of the growing season.

Another interesting feature of Figure 3 is the result obtained by extrapolating the results back to zero concentration, as shown by the dotted line at the lower end of the curve. This extrapolation reaches the zero value approximately two weeks after the leaves formed, rather than at the time when they began to form. Apparently new leaves do not accumulate sulfate during the early stages of growth, or else any sulfate accumulated is considerably diluted (on a weight basis) by the later growth of the leaf. The leaves would normally reach full size in approximately two weeks after the leaf buds open and would then remain approximately the same size during the remainder of the growing season. (They would not necessarily remain the same weight due to changes in water content, but analytical results were calculated on a dry basis.)

County-Wide Sampling Program

Since the leaves of both the ash and the elm appeared to accumulate sulfur dioxide continuously as a function of total exposure, samples were collected in different areas of Harris county and were analyzed to measure relative pollution levels in different sections of the county. The same type of collection and analysis was carried out with pine needles, since it has been reported that pine needles are also capable of reacting to sulfur dioxide and of storing the reaction products as a sulfate-containing material.[7]

Samples for these three species of trees were collected throughout the county, collecting the pine needles during the wintertime and the ash and elm samples at the end of the growing season just before the leaves fell from the trees. All samples were dried to constant weight, leached with hot water, and the extracts analyzed for both sulfate and sodium by the procedures described previously. Figures 4, 5, and 6 show the results obtained. In all cases, there appeared to be no consistent relationship between sodium and sulfate values, and thus it was assumed that sodium sulfate was not an important factor and that sulfate values were due primarily to sulfur dioxide. Furthermore, since sulfur dioxide is the best single indicator of overall pollution levels, the results are

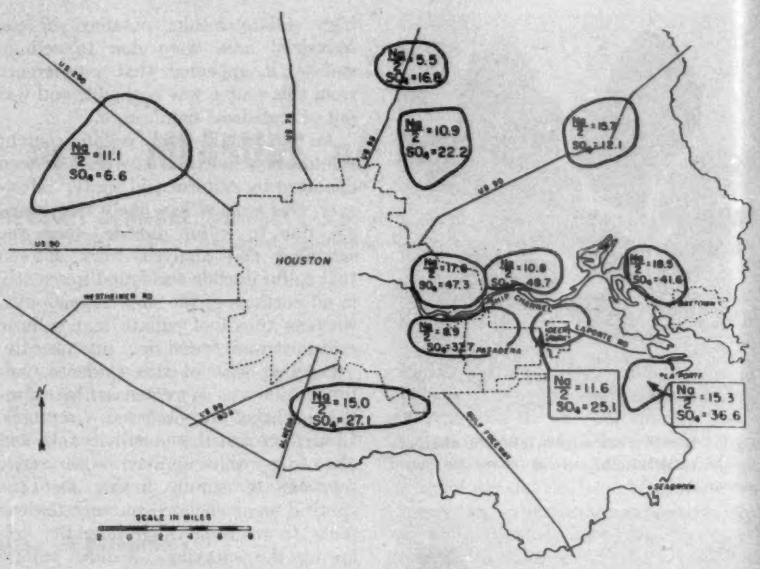

Fig. 4. Results of chemical analysis of ash tree leaves (micromoles per gram).

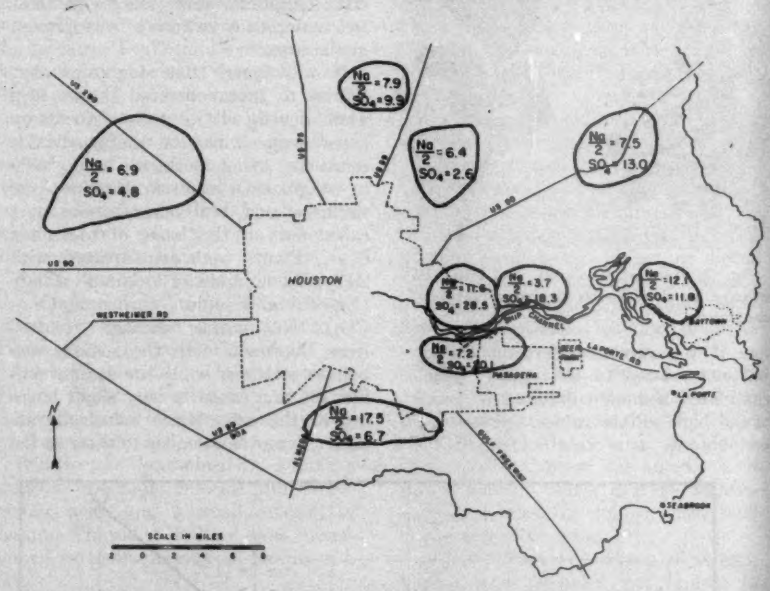

Fig. 5. Results of chemical analysis of elm tree leaves (micromoles per gram).

related to general pollution levels throughout the county as well as to sulfur dioxide specifically.

To make use of this principle, Table I was prepared, showing calculated pollution indexes for different areas based on pine, ash, and elm analyses. To calculate these empirical indexes, the average sulfate concentration from the three areas showing the highest value was arbitrarily assigned a value of 1.00. Average sulfate concentrations for all other areas were then divided into this value in order to obtain an empirical rating. For each section of Harris county, the pollution indexes calculated in this way agreed quite well with the expected pattern based on chemical sampling and analysis, meteorological factors, and distance and direction from known sources of pollution. It is felt that these indexes represent at least the same degree of precision as can be obtained in any other way, and that the precision is much better than that obtainable with some other techniques.

No consistent pattern was evident in the variations between indexes based on different species of trees, and therefore an over-all average was calculated by merely taking the arithmetic average for the three species of trees.

Conclusions

The results obtained in this study indicate that sulfate content of vegetation samples can be used to obtain

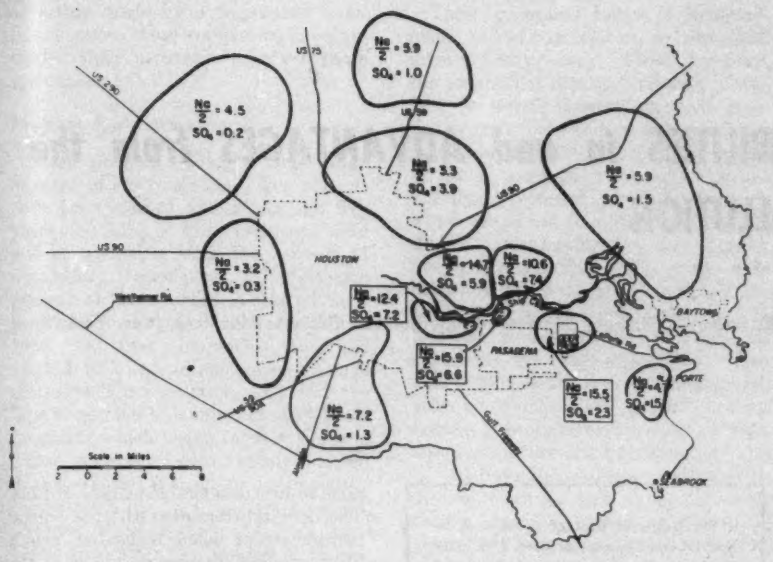

Fig. 6. Results of chemical analysis of pine needles (micromoles per gram).

Table I—Index of Pollution from Vegetation

Area	Ash	Elm	Pine	Average
North of Ship Channel:				
Galena Park-Port of Houston-Jacinto City (assigned arbitrary value of 1.00)	1.00	1.00	1.00	1.00
Green's Bayou—Channelview	1.03	0.64	1.17	0.95
E. Houston and Mt. Houston Roads (8–12 mi north of area 1)	0.47	0.09[a]	0.66	0.57[b]
Aldine Road—Rt 59 (14–17 mi north of area 1)	0.35	0.35	0.17	0.29
South of Ship Channel:				
Pasadena-Manchester-Harrisburg	0.80	0.71	1.22	0.91
Deer Park Area	0.53	n. a.[c]	0.39	0.46
La Porte Area	n. a.[c]	n. a.[c]	0.25	0.25
East of Ship Channel:				
Baytown and up to 3 mi north of Baytown	0.88	0.41	n. a.[c]	0.64
Along Rt 90, 9–13 mi north of Baytown	0.26	0.46	0.25	0.32
West of Ship Channel:				
Almeda and Almeda-Genoa Rds. (6–10 mi ship channel)	0.57	0.24	0.22	0.34
Northwest Harris County (20–25 mi northwest of ship channel)	0.14[d]	0.17[d]	0.03[d]	0.11[d]

[a] Based on samples of only three elm trees found in the area, and therefore of doubtful significance. Other values based on a minimum of five trees in each area.
[b] Omitting doubtful value for elm trees.
[c] n. a., not available; few or no trees of the species were found in the area.
[d] Analytical results were near the limit of sensitivity of the analytical method, and therefore of doubtful significance.

$$\text{Index of pollution} = \frac{SO_4 \text{ concentration for particular area}}{SO_4 \text{ concentration for Galena Park-Port of Houston-Jacinto City Area}}$$

a semi-quantitative measure of the long term exposure to sulfur dioxide. To the extent that sulfur dioxide is also related to over-all pollution levels, this can then be used as a general indicator of pollution. In the study made in the Houston area these data were used to calculate pollution indexes in different areas of Harris county, in order to determine relative pollution loadings. It is felt that these data provide the best means of making such comparisons and are much better than data obtained with a mobile laboratory. Permanent sampling stations might offer a means of obtaining more accurate results if a sufficient number of stations could be operated to provide thorough coverage of the area, but unless there were a great need for such information, the cost of a large number of permanent sampling stations would be prohibitive. Certainly for a survey in which only limited financial resources are available, this method offers the best possibility where applicable. The comparative ease and economy of obtaining data are major advantages. Also, trees work day and night as continuous sampling devices, and require no electric power and no maintenance. The results represent the cumulative effects of continuous exposure over a known period of time, with a continuity which cannot be obtained with a mobile laboratory and can only be approached with continuous recording equipment due to interruptions by breakdown, power failure, etc. The major disadvantage is that the cumulative results give no indication of short time peak values that occur during the sampling period.

It is not known to what extent similar techniques might be applicable in other locations. However, sulfate analysis has been used by other investigators to measure exposure to sulfur dioxide and it is probable that similar techniques could be employed to advantage in other locations.

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APCA ELECTIONS HELD AT MEETING

Four vice presidents were elected to office at the 53rd Annual Meeting. They are: Dr. W. L. Faith, First Vice President, Louis E. Bunts, Vice President of Control; Vernon G. MacKenzie, Vice President of Research and Education; and C. C. Tate, Vice President of Industry.

Howard C. Davies was re-elected as Treasurer of APCA for the 10th succeeding year. Mr. Davies recently retired as Treasurer of Mellon Institute.

INDUSTRIAL RESPONSIBILITIES *in and* ADVANTAGES *from the* CONTROL *of* AIR POLLUTION

MARTIN D. BARR, Financial Planning Department, International Business Machines, New York, N. Y.

Today, air pollution is a problem which is in the process of being solved, but is not yet conquered. The problem and methods for its solution are viewed in different ways by industry, the cities, states, federal agencies, and their employees. The engineer, chemist, farmer, and executive all agree, however, that the final solution revolves around the control and abatement of air pollution. The hypothesis in this paper is two-fold: (1) industry does have certain responsibilities in the control of air pollution; and (2) there are advantages that will accrue to industry from their acceptance of these responsibilities.

This paper is not basically concerned with either the polluting contaminants or with the control methods employed for their removal from the atmosphere. Nor, is it concerned with the costs arising from control programs and research of various types. Cost savings will be mentioned, however, in the discussion on the advantages of a control program.

Responsibilities and Advantages

Bias

Since much of the material included here is based upon the questionnaire shown in the Appendix, it is necessary to comment upon some possible biases which arise in the questionnaire, especially as the answers to the questionnaire present a picture of industrial actions and attitudes in the control of air pollution. These biases arise from the following:

1. the size of the questionnaire
2. the choice of companies
3. the location of these companies
4. the make-up of the returns

The questionnaire was sent to 250 companies in an attempt to cover a representative sample of American industry. However, while it covered the main sectors of industry in that the oil, steel, paint, rubber, plastics, and other metal companies were covered, in point of size, it was deficient. A questionnaire which covers such a minute percentage cannot hope to gain or result in a truly accurate picture of the actions of American industry.

This is compounded by the choice of companies and the location of these companies. Due to the subject of the paper, this questionnaire was sent to companies which were engaged in manufacturing, above average in size, and mainly in the eastern part of the country. By manufacturing, we mean companies whose main business is the conversion of raw materials into a finished product. Companies of this type were chosen because they are more likely to have had experience with air pollution control than a firm engaged in fabrication or extraction. The limitation to industrial firms also ruled out dumping and other activities who by their operations are connected with air pollution.

Companies above average in size were chosen because of a familiarity with their names or operations. Also, it was expected that companies of this size would have been engaged in some way in air pollution control. This caused a definite bias which will be seen in the general discussion of industrial control programs. Almost all companies returning completed answers maintained control programs and had done so for considerable lengths of time. This definitely disagrees with the general picture except where legislation exists. Most small companies do not have the wide and far-reaching programs carried on by large corporations. They lack both the research and the money. This will be returned to later.

Eastern corporations were chosen because of the time element. However, since action in the more densely populated and heavier industrialized area is likely to be more complete, a true picture of the entire country is not shown. This factor is minimized by the fact that most of the companies replying are of a multi-plant nature and have operations in all sections of the country.

There were 133 returns out of 248 which reached the companies, or 54%.* These present the possibility of a misleading answer due to their make-up. It is only natural that companies who have taken action should answer and those who have delayed should have remained silent. It appears from the sample where 123 companies or 92.5%, had programs, that it is the prevailing state of affairs. Regretfully, most companies in the United States at this time do not carry on programs. It was this large majority which did not answer the questionnaire and yielded an erroneous picture.

In summary, because of the size of the questionnaire, and the type of company who answered it, a biased picture is presented of the prevelance of acceptance by industry of its responsibilities in the control of air pollution.

General Programs

On the basis of the questionnaire, where 92.5% of the companies had programs, the contents of these programs will be examined. Ninety percent of the companies having programs, operate in areas where there are state or local control regulations. However, in most cases, those companies which are multi-plant in nature are not covered in all

This paper is part of a thesis in industrial management presented in 1959 to the faculty of the Wharton School of Finance and Commerce, University of Pennsylvania, by Mr. Barr in partial fulfillment of the requirements for the degree of Bachelor of Science in Economics. The Editors are pleased to be able to present it to their readers and encourage the submission of such original work on air pollution control.

* In two cases, the companies had ceased business.

operating areas by a legislative code. In the main, these companies have extended their programs to cover these operations.

Program Age Varies

These programs cover a large range in point of starting time. Ten percent have been started within this last five years and 50% of these programs were put in operation after the passage of controlling regulation. Twenty-two percent of the companies started their programs in the period between 1949 to 1954. Of these companies, 60% had started their programs before passage of controlling regulation. By far, the largest number of companies (68%) had programs which began over 10 yrs ago. These programs were mainly started during World War II or immediately thereafter. In 13% of these cases, however, these programs were not instituted until after the passage of legislation. This is counterbalanced by an equal number of companies who have programs where no authority exists at this time.

It is here, that a bias has appeared in the questionnaire. The apparent picture given by the above statistics shows industrial action mainly preceding the passage of legislation. It must be remembered, however, that the companies returning answers are mainly large in size and are more in the public eye. They also have more financial backing and could take action more easily than smaller companies.

Affect Employees and Public

These programs are for the controlling of pollution both internally and in the outside atmosphere. These programs have an effect therefore on both company employees and the public.

It is interesting to note, that of the companies recently starting programs (under five years old), all of them work with the authority in carrying out and improving their programs. Yet, in companies having started programs five to ten years ago, this drops to 81.5%. In companies whose programs are over 10 yrs old, the percentage working with the control authorities drops slightly to 79.5%. This decreasing amount of contact between companies and the authority is not unusual. As the company's program has been perfected and problems have been solved, there is less and less control work existing. This solving of company problems means that the co-operative work no longer becomes necessary. However, this does not mean there is no longer contact between the parties. There are still equipment inspections by the authority, reports from the firm, and work on general community problems.

These programs follow a heterogeneous pattern in relation to inter- and intra-industry work. First, however, the program of the oil companies in this field is worth mentioning. All companies contribute to and work with the American Petroleum Institute which carries on research in this field. It has developed efficient control measures which are in use at most refineries. Of the companies having programs of under five years duration, 75% work with other members of their industry for the solving of common problems. In this way, they obtain the use of previous experience by other companies. This falls to 50% in the area of working with other companies in their plant operating areas. A probable cause of this is that many plants are of a branch nature and do not have the necessary authority to discuss work of this type. In companies having programs of five to 10 years, only two-thirds (66%) work with other members of their industry and these are mainly in the chemical, oil, and utility fields. Again though, only 50% consult with other local industries in the solving of area problems. In companies with long standing programs, the percentage working with other members of their industry, returns to 75%, while the number working with other local industries rises to 60%. This shows that a realization of the value of working with local industries must have occurred.

Responsibilities

The previous section has given a picture of industrial programs in the control of air pollution. Most of the companies in the questionnaire have accepted their responsibilities whether by force or choice. However, as mentioned previously, the main segment of American industry is not on a level with this selected sample. The responsibilities industry must incorporate in their control programs in order to change the public attitude and prevent compulsive legislation is the subject of this section. Following this, the advantages resulting from the acceptance of these responsibilities will be discussed.

Responsibility means something for which someone is responsible. It may be a condition, a duty, or an obligation.[1] What are the responsibilities of industry in the control of air pollution, which in the eyes of the public have not been accepted? The following quotations describe them in broad form.[2] They will be summarized later.

> Industry has responsibility in air pollution control to its employees, its stockholders and the public. Progressive companies will include adequate pollution control facilities as a part of new unit design. Cost of installation and operation of such facilities should be considered a necessary cost of doing business.
>
> Air pollution is a problem that industry must constantly consider. It requires investment in new equipment and research and, also, careful operations and adequate maintenance of existing equipment.
>
> Air pollution is industry's own problem and too often they buy equipment or proceed to do a particular job without thinking of the effect of its exhaust.
>
> In the immediate future, it will be industry's responsibility to solve its air pollution problems. This should be done on a voluntary basis or it will be forced on industry by local, state, or federal authority.
>
> Industry, in general, has an obligation to its employees and surrounding neighbors to minimize its effluents whether it is in the form of air pollution or water pollution.
>
> Air pollution is an industrial responsibility which we have not shouldered, hence government legislation unrealistic and poorly planned.
>
> . . . it is important that industry continue to contribute its technical and administrative talents in carrying out the program.
>
> Like safety and industrial hygiene, an air control program must be considered an integral part of today's business.
>
> Our company's position is that it is a management responsibility as a good citizen to control stack gases and other air-borne effluents so that we do not offend the people in the community. We believe that people have a right to expect good conduct in this as in other areas of our business. Industry must realize that unless this concept is accepted voluntarily and implemented, it will be accomplished by law. Thus, without compulsion, industry should get its house in order and derive credit.
>
> Industry must take an active interest in air pollution activities, otherwise a community program as a whole will be ineffective.

In summarizing the responsibilities indicated by these quotations, they may be divided among primary and secondary. The primary obligation of the company is to establish and continue a control program; while secondary responsibilities exist, to the public, employees, and stockholders. Also inter- and intra-industry responsibility exists. The primary responsibility of a program exists because of a moral obligation. The old and the new Testaments state that, "Thou shall love thy neighbor as thyself" and "all things that you would have men do to you, you should do for them."[3] Also, if the company is causing the problem, it is legally respon-

sible for the immediate cessation of the disturbance.

The other responsibilities arise out of this primary one and determine the breadth of the program. The civic obligation concerns both the public and the control authority. The company should educate the public so that they have an understanding of the problem and an appreciation of the company's work. The company must also continually work on improving the control of its own situations. This obligation also includes the requirement of co-operating with the authority in all ways, meeting its requirements, and taking advantage of its services. Your neighbor is entitled to the same treatment as you desire from him. It should co-operate with the authority because only in that way can true improvement be made. The company will gain the respect of both the community and authority and will be able to carry on operations freely and with good public relations.

Responsibility to Stockholders

Their responsibility to the stockholder exists because of the pecuniary relationship between the two. The company must maintain a program that will maintain the company's earnings and not hinder its operations. Since a lack of air pollution control can yield hindering and expensive regulations and may hurt the profit potential of the company, there exists a responsibility on the side of the company to install an efficient and voluntary program.

The third responsibility which an air pollution control program must meet involves the employees of the company. This involves control both inside and outside of the plant. The program must provide both clean and safe working conditions. The workman's compensation laws hold companies responsible for injuries of sickness from causes of this type. The employee is entitled to receive the same consideration given people outside of the plant. Machinery operation training, safety, and industrial hygiene are continually stressed and improved upon in industry. The employee is entitled to the same consideration in relation to the air he breathes while at work.

Control programs also involve a responsibility to work with other companies both inside and outside a particular industry. Inter-industry work, as shown by the questionnaire, is done by approximately 60% of the companies. This responsibility of working with other local industries involves the extension of more authority to branch plant managers by the company. Since the companies are in the same area, by working together in solving common problems they will improve the efficiency of their programs and reduce friction with both the public and the control authority. This is not a legal or moral obligation as exists to the public, employees, or the stockholder, it is rather a matter of common sense that companies should work together.

It is surprising that companies feel more of an obligation to work with other members of their industry, as is shown by the 75% in the questionnaire. This situation exists because such work is done from the home office through trade associations and yields more directly applicable information. In doing work of this type, they reduce the likelihood of legislation and learn more efficient methods. The great hindrance to accepting an obligation of this type is the fact that competitors will gain access to confidential information. Yet, if discussions and research are limited to common problems, this fear has no basis. Co-operation of this type is demonstrated by the National Council for Steam Improvement, which is the association representing the pulp, paper, and paperboard industries. Their studies are limited to obtaining data on recovery processes, abatement methods, and attempts to determine the magnitude of the air pollution problem. It is at present limited to the kraft industry.[4]

Thus, an air pollution problem requires the existence or establishment of a control program. This program in its operations must meet certain legal and moral responsibilities to the public, the company employees, and to the stockholders. The program should also include inter- and intra-industry co-operation as a means of obtaining more efficient control.

Advantages

It is natural that many companies regard a program involving the above responsibilities as a waste of time and money and therefore, do the minimum required of them in controlling pollution sources. For many companies look only at the balance sheet side of an investment, and from this viewpoint air pollution equipment does not appear promising. Also, the operation of a far-reaching program does require the time and energy of personnel whom the company feels should be used for more important considerations. Yet, the advantages from an air pollution control program are wide and varied. They may be divided between economic, public relation, and employee advantages.

Of the companies in the questionnaire, 77% felt that their programs had reduced or removed the possibility of restrictive legislation and litigation. That litigation would be removed by an effective program requires no deep analysis. When control is good, there exists no possible grounds for litigation by either the public or the authority. The companies felt that the possibility of legislation was reduced by their actions, but not removed. This feeling exists because legislation is rarely aimed at a particular company, but attempts to set up requirements for the community. One of the advantages, therefore, of a control problem is the reduction of litigation and legislation which may hamper operations, cost money, and lose valuable operating time. To go even further, an effective program may be the only factor which permits the company to remain in an area.

Where the programs followed by the companies have included the education of the public both as to the problem and the preventative steps being taken, 95% felt that their relations with the public in their plant operating area were improved considerably. Since the people residing near the plant are those from whom complaints originate about operations, their goodwill and understanding is vital. Companies who because of tardiness in beginning or inefficiency in operating their programs, lose the support of the public, find that it is a long time before they regain their former high standing. These two advantages of public relations and reduced legislation and litigation are strongly connected. For, when people understand and appreciate a company's problems and efforts, they are willing to wait before instituting legal action. An example of this is Lorain, Ohio, where a beryllium plant was almost forced to leave town because the public feared the toxicity of the fumes and were not informed of the company's corrective actions.[5]

Morale Raised

Another place where a well run program brings returns, is with the employees. Sixty-eight percent of the companies felt that their employees were affected by their programs. The employees were affected in many different ways, most of which were advantageous to the company. The programs have resulted in improved working efficiency and conditions, higher morale, and less absenteeism and sickness. They also make the employees conscious of their responsibility to the public. Air pollution control is very closely tied to safety and industrial hygiene, as they all deal with the same general area. Due to the program, the company obtains more and better work from its employees, has less lost time for sickness, and instills in its employees a sense of pride in the company. The program also reduces the number of grievances and provides public relations people in the form of employees discussing their company with the public.

An example of the reduction in absenteeism and sickness which can be ob-

tained is shown by the Saint Joseph Lead Company which operates large mining interests in sourthern Missouri. By reducing sickness, the company also avoids the costs of replacement training and lowered output during this training period. It should also be noted that a program which provides good working conditions will reduce labor turnover. Saint Joseph has reduced its turnover from 250% in 1918, to 6.5% last year, including severance by death and pension.[6] The tremendous savings inherent in a reduction of this magnitude, does not require further discussion.

In 1923, the cost of sickness and absenteeism was $3.51/$100 of payroll. At that time, the safety department, which included air pollution control, spent $.10/$100 of payroll. By 1956, even with greatly increased compensation payments and wage rates, the cost of sickness had decreased to $.57/$100 of payroll. This decrease is attributed to the great increase in company spending for safety which now amounts to $.70/$100 of payroll.[6]

Economic Advantages

The final group of advantages which a company receives from accepting the responsibility of an air pollution control program, are economic in nature. The first of these is the recovery of materials which may be reused or sold. It is admitted that advantages of this type are specialized items and not all companies will receive benefits. Yet, 59% of the returns reported economies of this type. In most cases, the amount received in dollars was not tremendously large, but it does provide a return on the investment. These companies are located in the oil, brewing, paper, chemical, paint, rubber, electric utility, and metals industries.* In the electrical utilities it is the recovery and sale of fly ash, and in oil it is the prevention of hydrocarbon losses that provide these returns.

Only 18.5% reported an increase in land values because of their programs. I feel that this is a biased answer because of a lack of information on the part of company officials. When a company becomes situated in a location, it intends to stay and the increase in land value becomes of concern only if a move is contemplated. However, anything which makes an area nicer to live and work in, raises the land values. This is exemplified by land values in tenement districts after rebuilding.

In the reduction of soiling and corrosion of materials and structures, 75% reported a definite advantage. Many of the exhausts which are prevented by air pollution control are composed of materials which have oxidizing and debilitating effects. Other exhausts yield nothing but a film of dirt over everything in the vicinity and thus give rise to extra cleaning expense.

In Louisville, Kentucky, an experiment was performed, demonstrating the effect of air pollution metals. Steel springs were mounted in different parts of the industrial section and exposed to the atmosphere. Those which were in the direct path of winds from the pollution area deteriorated more rapidly than the others. The effect of the outside atmosphere has not been determined and this test is not exact, but it does show that air pollution can be damaging.[7]

Clearly related to this, is the lowering of plant maintenance costs which 31% of the companies reported. As there is less soiling and corrosion, there is less cleaning and repair work to do. The subject of plant maintenance costs is two-edged, however, and many companies reported an increase in them, due to the expense of servicing the program.

Fire Hazard Decreased

A decrease in the fire hazard was reported by 30%. This, like the recovery of materials, is a specialized situation depending on the pollutants. It exists mainly in the chemical and paint industries where the program removes flammable fumes from the air.

The final advantage noted is related to public relations and the company employees. The reduction or removal of objectionable odors through a program was reported by 64% of the companies. The removal of odors brings a halt to community complaints and produces more pleasant working conditions for the men. The result is less litigation, friendlier neighbors, and higher morale.

The advantages of air pollution control to a company are many and varied. They are economic, public relations, and employee relations. It must be remembered though, that the public relations and some of the employee advantages will not exist where compulsion has been necessary. Employee morale will not be raised quickly and the public will not feel that the company wishes to solve the problem.

Case Studies

Company A†

This is a small size firm which was started in 1936, just as the nation began to recover from the depression. They are a producer of lead, lead alloys, tin, and copper which are shipped in ingot form to other companies in this area. The company is a secondary producer, in that, they use the metal in any form for smelting and do not depend upon a supply of raw ore. Their material sources include such things as wornout storage batteries, lead piping, and electrical cables. At this time, the equipment in use at the plant includes blast and refractory furnaces.

The air pollution control problem of this plant has involved the spending of approximately 20% of their capitalization and a constant research effort. They employ a full time engineer who works on improving the current control process and spends a great deal of time in aiding other companies in their field, with control. The advantages to the company in following their program fall into two categories; public relations and internal improvement. They feel that the threat of both litigation and the setting of minimum standards by the city have been removed by their actions. Economically, it yields a return by lowering maintenance costs and trapping usable material which would blow out of the stack.

Their problem was a threefold one, involving smoke, odor, and the recovery of usable material. Approximately 10% of the metal placed in the furnaces went up the stack and until a method was devised for recovering this, no profit could be made. The odor resulted from the burning of rubber and sulfuric acid in the batteries and from the resin covering the electrical cables. The smoke was an inevitable by-product arising from the burning of fuel and the reduction of the various materials to the pure metal.

Begun in 1936

Control was begun in 1936 with the purpose of recovering the metal which had gone up the stack and prevented an economical operation. Wet scrubbers were installed and all emissions were diverted through them. They were 85% effective and the remaining 15% was released into the atmosphere. However, after the war, the section surrounding the plant was rapidly built up into a residential section. These people complained to both the company and the Air Pollution Control Board about the 15% which was still being released. The Board suggested that the company take further action and at no time took legal action against the company. Occasional meetings were held at various times to determine acceptable limits and to report on the progress being made. In the next step toward better control, the company installed afterburners on the stacks in an attempt to reduce the amount of pollutants escaping through further combustion. This lowered the amount of the smoke, but had no effect upon the odor. After a series of experiments, the company changed its entire control system and began using bag houses. These were extremely successful and

* Refer to Case Studies.

† Interview with President, November 20, 1958.

operated at an efficiency very close to 100%. On a normal day, nothing may be seen escaping from the stacks.

Complaints are no longer received even when there is a breakdown and pollutants are emitted, due to favorable public relations. The company is now operating at a profit and maintenance costs have been reduced due to a lowered amount of acid and resin discharge.

Company B*

Company B is a large national corporation which operates a plant in the Philadelphia area. Their local plant produces metals, plastic compounds, lead oxides, and paint vehicles. These last are non-pigmented coatings and varnishes. The company feels that considerable progress has been made on their particular problem, but that a stopping point has not yet been reached.

In June, 1955, a small pilot plant was erected for manufacturing the initial production batches of a latex emulsion paint. The production of the latex involved the use of an acrylic momomer, which are organic compounds. The company was aware that the monomer was highly aromatic and was toxic above certain levels of concentration in the atmosphere. Precautions were taken therefore to protect the plant personnel and keep the concentration far below that considered toxic.

The exhaust vents of the processing unit were conducted to the roof and the fumes passed through a small surge tank filled with a chemical known to be a good absorber of the monomer.

It was assumed by the management that this pilot plant run would proceed as smoothly as the previous smaller laboratory batches. However, shortly after production was begun, one of the batches reacted wrongly and an amount of unreacted monomer was released. Immediately, the company and the Control Board received complaints about odors emanating from the plant.

Corrective measures were taken at once by the company in consultation with the Control Board to prevent any recurrence. After laboratory research, the surge tank was filled with another chemical felt to be a better absorber. The pilot plant was then restarted and a great effort was made to standardize the batches. However, the human element was still present.

When at intervals, a reaction proceeded too rapidly and monomer fumes were discharged, complaints were received. The complaints were now increasing in both number and in demands for action. Several more attempts were made to utilize the surge tank in such a manner as to remove the problem, but they were unsuccessful.

The company, in conjunction with the Control Board, then came to the decision that more drastic steps needed to be taken. The ultimate decision was to purchase a catalytic combustion unit to eliminate the odor. Production was then halted until the unit was obtained and installed even though the company was losing a great deal of money.

Complaints Continued

The company feels that the neighbors were overly sensitized to the odor, but that a definite odor problem did exist. The company also found that complaints continued long after corrective measures had been taken.

Upon the arrival of the combustion unit and its installation, production was resumed. During this time, production had been expanded from a pilot plant to a full scale production unit. The odors were greatly reduced, but some still existed.

Since the fumes were highly inflammable, safety devices were installed to prevent any flashback from the combustion unit to the production unit. However, a reaction proceeded too quickly and an explosion resulted which did some damage but caused no injuries. To eliminate this hazard, the fumes were led first to a surge tank and then to the combustion unit. Again operations were halted by an explosion which damaged the surge tank. The next solution tried was placing two surge tanks in tandem along with dilution of the fumes with air so as to reduce the possibility of an explosion.

Still, under the best operating conditions, complaints were received by the company. Therefore, the company, on the recommendation of the Control Board, in an attempt to better its relations in the neighborhood, conducted a group through the plant and explained the steps they had taken to reduce the odor. At this time, the company felt that the smell might be apparent, but was certainly reduced.

As the monomer was then being stored at the plant prior to processing, steps were taken to avoid polluting the air during the loading and unloading of the storage tanks. This was brought to the company's attention through complaints made to the Control Board. Another facet of the problem pointed out by the Control Board, was that an odor can be objectionable to some, pleasant to others, and undetectable to a few.

To prevent the escape of monomer fumes during unloading, the company designed cartridges of granulated activated carbon. These were attached over all exhaust vents on the storage tanks and the delivering tank truck. They were extremely effective, but absorbed enough of the monomer to cause a considerable rise in the temperature of the carbon.

The problem was now presented that the carbon would become hot enough to ignite the fumes and cause a disastrous explosion. Jackets filled with dry ice were constructed around the cartridges and constant thermometer checks were taken on the temperature of the carbon. A man was assigned to watch these thermometers at all unloading operations; if the temperature rose above 100°F, unloading was halted until the carbon returned to a safe level.

Complaints now began to diminish although occasional ones were received by the company and the Control Board. However, periodically production errors were made and fumes were released causing another series of complaints.

Finally, the company began work on eliminating any odor which escaped from the catalytic unit. The solution was to run the unit at a temperature higher than normal. While this would insure combustion of all fumes, it also caused more rapid corrosion of the unit. The company at present has received no complaints for some months, but are still working on the elimination of some slight residual odor emanating from the combustion unit.

The company periodically sends out members of their managerial staff to interview families in the neighborhood to determine their opinions about the work that the company has done and is doing in odor removal. This type of survey was suggested by the Control Board and has proved quite successful. This survey serves a two-fold purpose, giving the company information on the frequency of odor emanation and reassuring the neighbors of the sincerity of the company. The net result has been that the neighboring community has changed from a group bent on limiting the activities of the company, to a group co-operating with the company in its attempts to remove an objectionable odor.

The company also feels that the services and co-operation of the Control Board were essential in solving the problem.

Company C†

This is a large public utility operating in a highly industrialized area of the United States. The company's operations have a tremendous effect on the atmosphere due to the large amounts of fuel they consume compared to other operators. They burn around 23% of the total liquid and solid fuels consumed. This discussion will be based on the general program followed by

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* Interview with Production Manager, November 4, 1958.

† Interview with Superintendent, November 14, 1958.

them over a period of years for the reduction of particulate emission, as part of their civic responsibility.

The main advantages in this program lie in the fields of public relations and economic return. The public relations aspect is clear, in that, the neighbors are also the customers. The economic advantage lies in lower maintenance costs due to decreased soiling and corrosion.

The main work has centered around the generating stations and involves the reduction of stack loading to the lowest point consistent with available equipment and good engineering practice. This has involved the installation of modern equipment in new stations and the modernization and correction, where necessary, of the older generating stations. This is accomplished through engineering studies and the maintenance of equipment in good operating condition at all times.

In its present operating setup, various types of fuel burning equipment are employed. These range from boilers fired with pulverized coal to stoker-fired boilers (vintage 1920–25) which, in the main, have been converted to oil firing. The use of pulverized coal is dictated by economic considerations as well as by the guarantee of a continuous supply. The furnace is fired by blowing the fuel directly into the flame. The fuel ignites immediately and the hot gases and ash residue pass to the stack. The major part of the fly ash is removed by mechanical collectors and/or electrostatic precipitators. The fly ash is sold to various concerns who use it in chemicals and cement. Thus, part of the expense is defrayed.

In 1949, the company combined the two units in order to obtain the optimum stack performance. The mechanical collector was followed by the electrostatic precipitator and they, operating in tandem, reduced the fly ash loading to approximately 0.2 lb/1000 lb of gas.

Converts Stokers

Prior to this, as part of its program to reduce emission of pollutants into the air, the company began converting the old stoker fired furnaces to oil firing. This step has resulted in greatly reduced atmospheric pollution near the plant and more flexible operation of the equipment. At this time, around 50% of the stoker fired boilers have been converted at a cost close to $3,500,000. While this program is highly successful, it cannot be extended to all equipment as in a national emergency oil might become unavailable in quantity.

In 1935, the company installed its first pulverized coal-fired boiler. This installation was in an industrial area and collectors were installed as a result of the company's belief in responsibility to its neighbors. Electrostatic precipitators were installed at a cost of $200,000. About 20 years later, the installation was modernized at a cost of $300,000, by the addition of a mechanical collector.

All control equipment purchased must meet rigorous specifications and undergo testing before installation. The company works with the manufacturer in improving his product and buys on the basis of efficiency. The location of the installation determines in a large part the desired efficiency. The most recent station built in a suburban area was designed for 98.5% efficiency, while industrial area requirements are normally lower.

Boilers Automatically Controlled

The company also works on the development and use of combustion indicating units. Units of this type are installed continually and today all pulverized coal-fired boilers are under full automatic control. By completely utilizing the fuel, maximum efficiency is obtained and the possibility of unburnt fuel acting as a contaminant is eliminated. Smoke detectors have also been installed on all stacks. These inform the operator as to the stack loading and sound an alarm when excessive conditions occur. The reasons for such occurrences are recorded and studied by the plant operations group.

Fuel selection is also a point of great concern to the company. All solid fuels are carefully sampled and analyzed to control their effect on the atmosphere. A high ash fuel increases operating and maintenance costs as well as aggravating the problem of ash collection and disposal. The boilers are tested three times yearly to determine their stack loadings. This allows corrective maintenance to be done in a more efficient manner.

Finally, their control program includes the education of their employees. This serves a dual purpose: (1) to improve their efficiency and (2) to make them more conscious of public relations as viewed in connection with air pollution.

Over a period of 20 years, the company has spent in excess of $9,000,000, to improve the atmospheric conditions surrounding its operating units. They believe the return in good will alone is worth the investment. They also feel that mutual co-operation between civic authorities and private operators is the best solution to the problem of air pollution.

Summary and Conclusion

Summary

In this paper, we have examined industrial responsibility in the control of air pollution and the advantages arising from such control. In this chapter, we shall draw certain conclusions regarding industry and air pollution.

Air is our most important resource. Everything that we do or use has some connection with air. Of the four fundamental resources of land, fuel, water, and air, air is the most limited in supply and cannot be replaced by other substances. Yet, air in the United States and the rest of the world is continually being polluted by different sources. In the United States, this pollution has been brought about by the industrial revolution and its products.

The public feels that industry is completely responsible for all pollution and ignores the flow of contaminants from domestic chimneys and automobiles. The public also feels that industry does not co-operate in anti-pollution work and must be compelled through restrictive legislation.

The highly publicized incidents of air pollution that occur have furthered this two-fold belief in industrial responsibility and the need for compulsion. The four incidents: the Meuse Valley, Belgium; Los Angeles, California; London, England; and Donora, Pennsylvania, have all resulted in legislation limiting industrial freedom. However, the Meuse Valley cannot be attributed safely to industry, because the concentrated population also uses coal as its principal fuel and produces the sulfuric acid fumes which were held responsible for the many deaths.

In Los Angeles, the problem, despite control of industrial contamination, both by choice and force, is worse today than ever before. The two culprits are the millions of automobiles and home incinerators in the vicinity. Industry did have a responsibility, however, to solve its air pollution problems upon knowledge of its existence.

In Donora, Pennsylvania, industry was responsible for the problem and had not accepted its responsibilities. The responsibility was proved by a Public Health Service Study and the incident resulted in a hardening of public attitude. This occurrence caused many cities and states, hesitant about passing laws, to proceed headfirst into control.

London, England is another place where industry is not totally to blame. The heating system used in British homes is the main cause of the terrible smogs which have killed hundreds and caused millions in property damage. Yet, the legislation passed has been aimed at industrial operations and controls all new installations.

Since World War II, legislation on the municipal level has been prolific and of a restrictive nature. State governments have also entered the field and passed laws controlling air

pollution. These laws vary widely according to industrial co-operation and acceptance of their responsibilities. The federal government entered the field in 1955, with the passage of the Air Pollution Research and Assistance Act.

Many federal departments are connected with or interested in air pollution. These range from the Atomic Energy Commission to the Department of Agriculture. The work under the Congressional act is carried on by the Public Health Service of the Department of Health, Education, and Welfare. This program emphasizes research, personnel training, and technical assistance on specific problems. Information has been collected by the Service and independent contract groups on the identification, effects, and abatement means of air pollution. Also, on the factors affecting atmospheric dispersal.

This act has no direct connection with industry as it specifically relegates legal responsibility for control to state and local governments. It will, however, provide a basis for reasonable legislation, provide industry with information leading to more efficient control, and help educate the public.

Legislation

It should be noted, that legislation becomes less restrictive when legislation is passed on a higher level. It is not aimed at isolated incidents but is designed to operate for the greatest good. Where industry has co-operated, public opinion is favorable and there is no need for compulsive regulations. The need here is guidance and the setting of reasonable requirements.

The acts of New Jersey and Oregon are good examples of the results of acceptance and non-acceptance of responsibilities. In New Jersey, where industry has co-operated, the legislation is reasonable and calls for industrial representation on the ruling body. Problems are treated individually, law contains no specific requirements, and in-plant surveys are conducted to determine the appropriate action. The co-operation of industry in accepting their control responsibilities has been the key to the passage and success of this legislation. It provides industry with a friendly atmosphere for expansion, means programs may be planned efficiently and guides them in their work.

In Oregon, the law is passed under the state police powers and operates uniformly throughout the state. Industry is not represented on the ruling body and actions may be taken as is needed for summary abatement, regardless of reasonableness and the existence of satisfactory and efficient equipment. This hindering legislation was passed because of public attitude and also acts as a deterrent to further expansion of industry.

These cases demonstrate that where industry has willingly accepted its responsibilities in the control of pollution, legislation is favorable toward them.

Local legislation is varied and communities tend to adopt the codes for other locales regardless of their present applicability. Where strong legislation is desired, the permit system is widely used as a means of forcing industrial control. Operating under the doctrine of "reduction at the source," it gives the authorities approval control over all new installations and all changes in existing operations. Plans must be submitted and are approved or denied. When the installation is completed, approval must be obtained for operation and the equipment is subject to continuing inspections. If poor performance is found at any time, the operating permit may be revoked and court action instituted.

The system says that industry cannot be trusted to accept and maintain its responsibilities. It forces monetary expenditures and the loss of valuable time by the weight of public opinion when the results are often unknown.

The important point, therefore, is the identification of the responsibilities which the public feels have not been accepted and its attempts to compel. This information was obtained in a questionnaire sent to different industrial firms. Certain biases exist in the questionnaire due to its size, the choice and location of companies, and the returns. It was sent to a smaller number of companies than is necessary to gain an absolutely true picture. The choice and location of the companies presents a bias because mainly large scale operations in pollution areas were chosen. These companies were more likely to have undertaken action than smaller, more isolated firms. The returns show a bias in that companies without programs hesitate to answer this type of question and thus prevent a balanced picture.

The great majority of the answering companies maintained control programs and operated in areas containing state or local regulations. The programs have been started anywhere in the last 30 years, with the majority in operation for over 10 years. The programs are for both internal and external atmosphere control. Most companies work with the control authorities, other members of their industries, and with local industry in the solving of common problems. It is interesting to note that as programs grow older, fewer companies work with the authority, yet, more interaction occurs both on an inter- and intra-industry level. The chemical, oil, and utility industries are particularly active in these fields.

These programs embody the responsibilities which industry must accept in controlling air pollution. Some of these responsibilities are legal and some are moral in nature. They exist to the public, the stockholder, and the company employees. The primary responsibility is the existence of a control program. It involves educating the public, adequate maintenance, research, and equipment investment. Out of the research responsibility arises the common sense obligation of inter- and intra-industry co-operation. Through this, better and more efficient methods may be obtained. The companies should co-operate with the authority in all ways. Without their aid and assistance, a community program may be ineffective. To the stockholder, the company owes the responsibility of avoiding all things which may hinder their operation. The employees are entitled to clean, safe, and enjoyable working conditions.

The acceptance of these responsibilities yields many advantages. They are related to public relations, the employees, and economics. The public relations advantages involve the reduction and removal of restrictive legislation and litigation and the improvement of company relations with people residing in the operating area. Another advantage is the high morale, improved efficiency, and reduction in absenteeism and sickness on the part of employees. This yields higher production and less lost time. Economic advantages include the recovery of material which may be reused or sold, an increase in land values, a decrease in the soiling and corrosion of materials, the lowering of plant maintenance costs, and the reduction in fire hazards and objectionable odors.

The case study chapter presents a picture of the programs operated by a national corporation, a small firm, and a public utility in their acceptance of responsibility.

Conclusions

In conclusion, I present four points for consideration. These have been discussed in both the text and the summary.

1 The public attitude that industry is responsible for all air pollution, is erroneous.
2 Where industry has accepted its responsibilities in the control of air pollution, legislation is reasonable and non-restrictive.
3 These responsibilities exist to the public, the stockholders, and the employees. There are also obligations for inter- and intra-industry co-operation.

4 Acceptance of these responsibilities yield certain advantages to industry. There are economic advantages, public relations returns, and employee advantages.

Appendix

Please indicate those questions not applicable to your company

1 Is there a state or local air pollution control authority in your plant operating area?

2 Does your company have an air pollution control program?
(a) Is this program directed toward control of internal conditions?
(b) Is this program directed toward control of substances released into the atmosphere?

3 If your company is a multi-plant operation, are all plants covered by this program?

4 How long has your plan been in operation?
—Over 10 years.
—Over five years.
—Under five years.

5 Prior to the establishment of the authority, did your company follow a control program?

6 Do you work with the authority in improving and carrying out your program?

7 Do you work with other companies in your industry for the solving of common problems in this field?

8 Do you work with other companies in your plant operating area to solve local problems?

9 Do you feel that the program followed by your company has reduced or removed the possibility of restrictive legislation and litigation; which would hamper your operations?

10 Do you feel that the program followed by your company has improved your relations with the general public in your plant operating area?

11 Does your program result in the recovery of materials which may be re-used or sold?

12 Has your program: (please check those applicable)
—Increased land values in your plant operating area?
—Reduced the soiling of materials and structures in and around your plant?
—Reduced the fire hazard in your plant?
—Lowered plant maintenance costs?
—Removed objectionable odors which may exist?

13 Has your program affected your employees in any way?

14 If so, in which of the following ways?
—Improved working efficiency
—High morale
—Less absenteeism and sickness
—Others (Please comment)

15 Any comments which you have upon industry and its relationship to air pollution will be sincerely appreciated.

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NATIONAL COAL ASSOCIATION

announces

Establishment of a new Air Pollution Control Department within its Marketing Division. This new Department desires to maintain a close working relationship with control officials, plant managers, government administrative bodies, civic groups, and technical and trade organizations in matters dealing with air pollution control.

Formation of an Air Pollution Control Department by the National Coal Association represents the first "grass roots" effort by a major industry to combat problems of air pollution. This new department offers advisory services of two experienced engineers, with field offices centrally located in Cincinnati, Ohio—serving 16 mid-western and southern states—and Colonia, New Jersey—providing service to the east coast.

The new Department, already at work with a number of air pollution control agencies, can bring to you an exchange of ideas in helping to solve your control problem.

NCA's industry-supported Air Pollution Control Department is available to serve you now. Send your inquiries or requests to:

Harry C. Ballman, Director
Air Pollution Control Department
Marketing Division
National Coal Association
Coal Building
1130 Seventeenth Street, N. W.
Washington 6, D. C.

INDUSTRIAL OVENS *Designed for Air Pollution* CONTROL*

P. H. GOODELL, Vice President-Sales, Catalytic Combustion Corp., Detroit, Mich.

Very few industries or manufactured products would exist today, were it not for the many functions performed by ovens, furnaces,† and dryers. Beginning with the drying, heat treating, and bonding of raw materials, through to final finishing operations on the completed product, ovens and furnaces are among the most versatile and extensively used items of modern plant equipment.

Although designed primarily to provide a specific temperature cycle, they also serve to contain and control side reactions or secondary functions, many of which have an important bearing on the overall result intended. Air, or gases of special composition, usually play a vital role in these heating operations to accomplish one or more of the following functions:

1. Provide proper combustion of liquid or gas fuels being used as the source of heat.
2. Transport the heat generated from the source to the working area or processing zone of the oven and at the proper temperatures.
3. Provide intended distribution of the heat to all areas, surfaces, or sections of the products to be processed.
4. Assist in the oxidation of oils, organic coatings, and binders that have been applied to materials in process.
5. Serve as the medium to safely dilute and carry away unburned fuel, evaporated solvents, and other flammable gases that may otherwise create an explosion hazard.
6. Avoid spill of combustible and odorous materials into the adjacent working areas of the plant.
7. Prevent contamination to the process and mal-operation of equipment from by-products that are not fully or permanently gasified during the cycle, and which characteristically create a fire hazard from accumulation of flammable condensate on concealed surfaces.
8. Maintain product surface characteristics by providing a protective atmosphere during the heating cycle to avoid metallurgical changes.

Having fulfilled its purpose, the oven atmosphere must eventually be exhausted and replaced. It is in this operation that fire hazard and atmospheric pollution occurs unless appropriate action has been taken to destroy the constituents reponsible for these results. Decontamination and efficient use of air in industrial ovens and furnaces will thus influence two important considerations, namely *Industrial Air Pollution* and *Plant Safety*. It is accordingly the purpose of this paper to bring these problems into focus, suggest the importance and magnitude of the problem presented, and offer recommendations for improving standards of operation that can be readily adopted for the benefit of all concerned, including the equipment manufacturer, user, and community involved.

A typical example will serve to illustrate the magnitude of the problem presented. Many ovens, with modern ventilation systems by today's standards, are used for continuous coating operations in the manufacture of laminated plastics, sand-paper, coated fabrics, metal food containers, and electrical laminations for motors or transformers. With high speed automation, these ovens are often called upon to handle 100 gph of typical hydrocarbon solvents with ventilation exceeding 20,000 cubic ft per min. Since ovens of this size represent a major investment, they are frequently in service 16 hours per day. A typical month of operation at normal running load will thus result in the delivery of 35,000 gal of vaporized hydrocarbons to atmosphere.

To view this figure in terms of atmospheric pollution or a similar situation having greater familiarity, the following comparison is offered to automobile exhaust emissions. At prevailing rates established by the U. S. Department of Public Roads, passenger cars consume an average of 80 gal of gasoline per car per month. This use results in approximately 800 miles of travel per car and simultaneously in the release of about 4.8 gal of unburned hydrocarbons to atmosphere. The latter figure is obtained from studies of representative car use by the Automobile Manufacturer's Association and other groups interested in air pollution control.

Seven thousand three hundred (7300) passenger cars operating a distance of 5,800,000 total miles on our streets and highways are thus required to release the amount of unburned hydrocarbons that may be discharged by a single industrial oven in a span of one month. (See Appendix "A" for details.) Although ovens of this size are the exception rather than the rule, several thousand ovens used for the sole purpose of enameling magnet wire each release over 50 gal of hydrocarbons per day (1200 gal/month), and many paint finishing ovens in the high production industries will release up to three times this volume of paint solvents. Another 100,000 or more ovens in 289,300 U. S. plants release an overall average of 400 gal per month, or an amount equal to hydrocarbon emissions from 83 modern 200 hp automobiles.

The constituents and resulting density of gases released per square mile of major urban area will vary widely, but the inevitable conclusion is reached that the problem is one of sufficient proportions to warrant investigation and corrective action in major industrial areas. From a user standpoint, it is also apparent that a tremendous amount of energy is being lost, presenting a very real challenge to individuals responsible for the selection and design of oven equipment to provide better energy utilization for future service.

Sources of Oven Hazards

The sources of air pollution from industrial ovens and furnaces are:

1. Unburned or incomplete products of combustion from fuel-fired heating systems.
2. Vapors released from solvents and other highly volatile hydrocarbons used in the process.
3. Heavy hydrocarbons or organic constituents such as resins, oils, waxes, etc., that may be vaporized or cracked at high operating temperatures.

The hazards requiring specific design

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* Presented at the 52nd Annual Meeting of APCA, June 22–26, 1959, Statler Hotel, Los Angeles, Calif.

† Ovens operating above 700° F are usually classified as furnaces.

Fig. 1. Multiple use of catalyst elements for processing hydrocarbon fumes in a large oven heating system.

and operating consideration from a safety standpoint are:

1 Release of unburned fuel.
2 Evaporation of flammable vapors in concentrations creating an explosion hazard.
3 Accumulation of liquid and resinous by-products, including hydrocarbons, often causing mal-operation of safety equipment, reduced ventilation, and secondary fire hazards.

Comparison of these tabulations will reveal that the contributing causes to air pollution and safety hazards are identical. This logically suggests the opportunity for simultaneous correction of both problems by initiating action that will destroy the basic flammability characteristics of the air contaminants near the point of origin. Catalytic oxidation offers such qualifications, as it is basically intended to function at elevated temperatures, providing complete destruction of combustible and organic type vapors regardless of their fuel-air relationship. Where and how catalysts should be applied to produce the intended result becomes a matter for further investigation. The important consideration is that singular action, properly directed, can accomplish two entirely diverse objectives, thus avoiding the need to assess nonproductive costs against air pollution control.

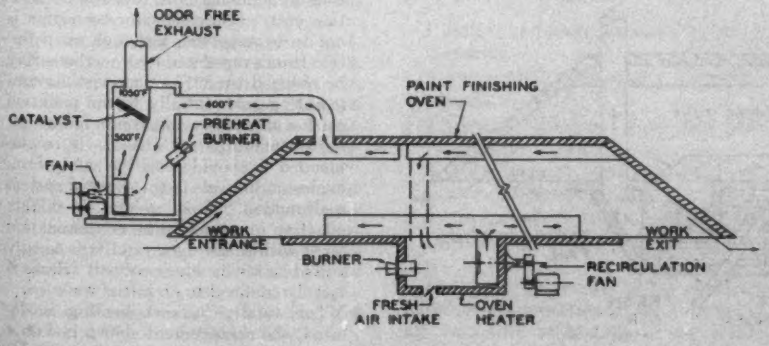


Fig 2.

Ovens Contributing to Air Pollution

Typical processes and types of ovens responsible for air pollution include:

1 Wicket type metal coating and lithographing ovens.
2 Continuous web type impregnation ovens for paper and textiles.
3 Wire enameling ovens, horizontal and vertical types.
4 Metal foil, band, and strip coating ovens.
5 Metal lamination or core plate ovens.
6 Oil burn-off ovens and furnaces.
7 Continuous dryers for glue and adhesives.
8 Monorail and pallet type ovens for metal finishing.
9 Cross bar and elevator type ovens for dip paint and varnish systems.
10 Foundry core ovens.
11 Wax melting ovens and kilns.
12 Brake shoe burn-off and bonding ovens.
13 Bonding ovens for mica, metal, and wood products.
14 Carbon electrode furnaces.
15 Dryers for pipe coatings.
16 Polyvinyl chloride curing ovens.
17 Metal chip dryers.
18 Dryers and baking ovens for packaged food products.
19 Grain dryers and roasters.
20 Dryers for fish by-products.
21 Ovens liberating toxic or poisonous, combustible type vapors.
22 Miscellaneous cabinet or batch ovens for general purpose use.

The above ovens may use steam, oil, gas, or electric heating systems with one or more heating zones provided, depending on the temperature cycle required during the process. Heat transfer is occasionally provided by radiation, although more often by forced convection. One or more heating zones may be employed depending on oven size and process needs. Air may be circulated through these zones only once or it may be recirculated many times with a portion being continually exhausted to maintain air contaminants below acceptable levels within the oven atmosphere.

To date, most oven exhaust ventilation is provided primarily to meet established safety standards, with little

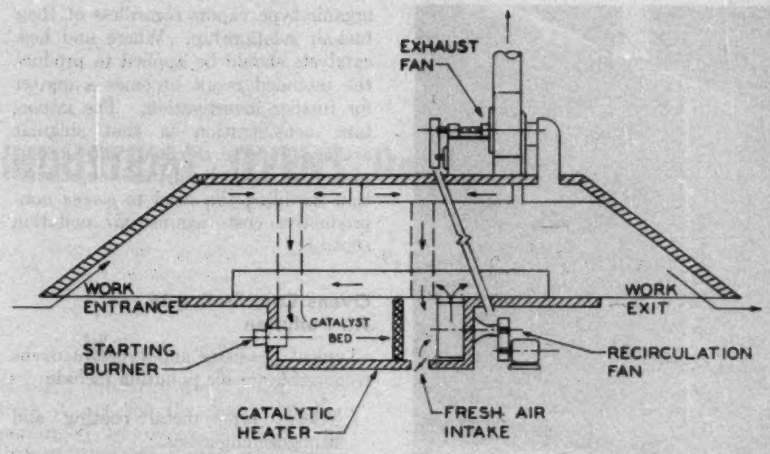


Fig. 3.

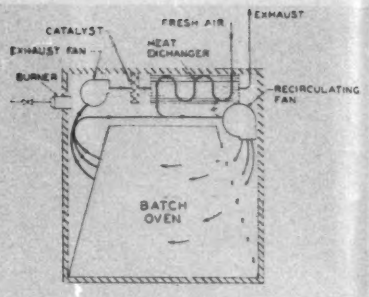


Fig. 5.

or no regard for air pollution that may result. Excessive amounts of vent air may be used initially, if plant growth is expected to impose increased future loads on the oven operation. However, when peak loads are reached, typical hydrocarbon fumes are commonly vented so that vapors from each gallon of evaporated product are diluted in 10,000 cu ft of air. This reduces the potential energy concentration as for typical paint solvents to:

$$\frac{120{,}000 \text{ Btu/gal}}{10{,}000 \text{ Std cu ft}} = 12 \text{ Btu/Std cu ft}$$

Since the lower flammability limit for most hydrocarbons is reached at approximately 52 Btu/Scf, the above assures dilution below 25% of the LEL (Lower Explosive Limit), as required for insurance approval.

An analysis of heat utilization in most industrial ovens will reveal that upwards of 70% of consumed energy is spent for safety considerations and often as little as 10% for the primary heating objectives intended. This ratio of productive to nonproductive expense bears investigation as changes in oven ventilation are considered for the addition or incorporation of air pollution control. This view is supported by analysis of the recoverable "fuel value" present in the fumes to be exhausted. For example, an oven vented at 25% LEL carries away energy that is capable of raising its own temperature 660° F since the thermal capacity of dry air is such that each Btu released in a cubic foot of air at standard 70°F density will raise its temperature approximately 55°F. (Appendix "B".)

$$55°\text{F} \times 12 \text{ Btu/Scf} = 660°\text{F temp rise}$$

Since ovens are basically heat consuming devices and their exhaust gases inherently contain additional sensible heat from the process, it appears most logical to evaluate available energy in relation to needs, when considering means for air pollution control.

Destruction of air contaminants frequently cannot be provided at oven operating temperature; however, the energy released by their oxidation to inert carbon dioxide and water vapor will very often exceed additional heat demands. This process, often referred to as "flameless combustion," occurs at temperatures ranging from 450°F to 750°F, and irrespective of the fuel-air relationship. Fundamentals of catalysis and the types of catalysts available for use in oven and furnace applications have been covered in previous technical papers. Figure 1 illustrates one standard type now extensively used by leading oven manufacturers.

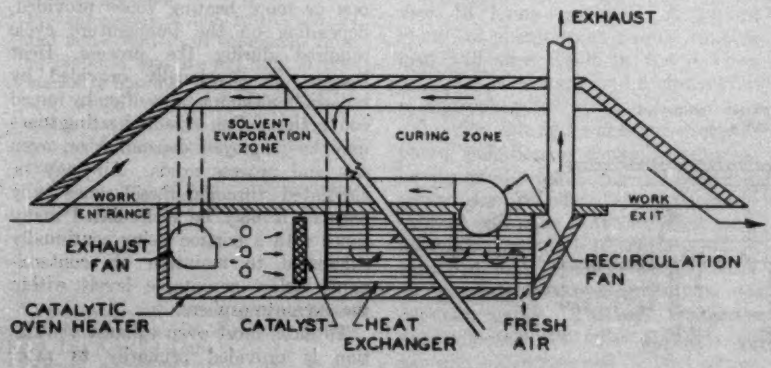


Fig. 4.

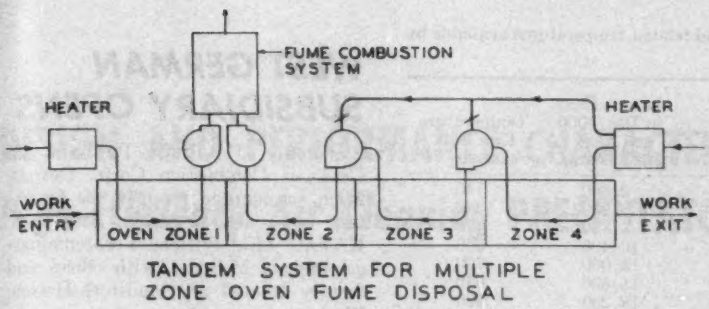
Methods of Applying Catalysts

Five basic methods for applying catalysts to ovens are recommended to meet the objectives previously described. Selection will depend upon design and operating temperature of the oven heating system, available space, method of control desired, and cost considerations.

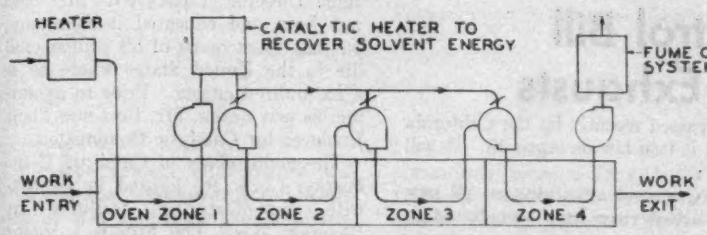
1 A catalyst system operating entirely independent of the oven heater is shown in Fig. 2. This arrangement provides air pollution control without heat return to the oven and may be easily added to existing ovens. Condensate problems external to the oven are eliminated and heat release in the catalyst can be used to measure the adequacy of flammable vapor dilution. A predetermined exhaust volume, suitable for peak solvent loads, is usually employed to meet safety requirements and fumes are preheated to the minimum entry temperature required for reliable operation of the catalyst. Heat from the oxidized exhaust gases can be used for an external process, such as winter heating of building make-up air, water-drying operations, or in a waste-heat boiler or superheater.

2 Most ovens of modern design will permit use of catalysts directly in the oven heater as shown in Fig. 3. In this location they can effectively supplement the usual burner, avoid duplication of housing, preheat equipment and controls, thereby reducing both fuel and installation cost. Complete odor correction is not to be expected, although air pollution from evaporated hydrocarbons may be reduced by 80% or more, thus contributing substantially to air pollution control objectives, and at minimum cost. Separate means for exhaust is recommended to provide positive safety from explosion hazards in the event of system malfunction. This system is highly effective in reducing the contamination level within the oven, and it is ideally suited to ovens where solvent release is largely confined to an initial zone.

3 When totally indirect heating is desired, the arrangement shown in Fig. 4 is very often used to take the oven air



TANDEM SYSTEM FOR MULTIPLE ZONE OVEN FUME DISPOSAL



CASCADE SYSTEM FOR HEAT RECOVERY AND FUME DISPOSAL ON MULTIPLE ZONE OVEN

Fig. 6.

supply and recirculation streams across a heat exchanger. Heat is then supplied to the system by the combined use of a burner, catalyst, and exchanger in the exhaust system for maximum energy recovery. This arrangement avoids return of contaminated gases to the oven in event of equipment malfunction, and provides the ultimate in a clean oven atmosphere, with external air pollution control.

4 Batch type ovens usually handle much smaller heating loads than continuous production ovens and consequently their air handling systems may be proportionately smaller. Very often the rate of solvent evaporation is unknown and therefore cannot be directly related to calculations for the Lower Limit of Flammability as previously indicated. Accordingly, recognized safety standards call for the use of 380 Cfm (at standard 70° condition) for each gallon of flammable products to be used in a representative oven charge. Confirmation of the resulting hydrocarbon dilution should be confirmed by analysis of the resulting exhaust gases or by checking the heat of combustion provided in the Catalytic heater as shown in Fig. 5. This system provides heat recovery from the decontaminated exhaust gases, also assures location of the exhaust fan at a point where condensate cannot accumulate to impair safe and reliable operation.

5 Large multiple zone ovens may employ air decontamination and heat recovery on individual zones by any of the exhaust and heating arrangements previously described. In addition, two or more zones may be treated in combination as illustrated in the flow diagrams shown in Fig. 6. Selection is primarily influenced by desired temperature gradients, location or distribution of the major solvent and fume releases, and related cost considerations.

All of the above systems have been field proved with results demonstrated to the satisfaction of interested air pollution control authorities. In most cases, cost considerations are substantially improved by incorporating the air pollution control system as an integral part of the initial oven design, thus centering responsibility with a qualified oven or furnace manufacturer for full and complete co-ordination of the heating, air pollution control and safety considerations, prior to installation. In this manner, expected results can be readily appraised by the user, insurance underwriter, and air pollution control authority having jurisdiction. With qualified handling, this practice offers the opportunity to improve prevailing standards of oven operation by providing:

1 Better and more consistent heating results.
2 Substantial reduction in maintenance.
3 Greater freedom from fire and explosion hazards.
4 Reduction in fuel demand and overall operating costs.
5 Air pollution control as the by-product result of efficient operation.

Few if any other industrial processes afford such opportunity for improving air and fuel utilization in the years ahead. Ingenuity will be required by the oven builder in adapting the best or most economical air pollution control system to each individual type or temperature range of oven to be used. Wholly new types of ovens may also be developed to properly co-ordinate and utilize the full advantages herein described. Extension of today's standards for the prevention of atmospheric contamination from industrial oven and furnace emissions provides the key to future accomplishments anticipated in this field.

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Appendix A

1 Hydrocarbon emission in the exhaust from a processing oven handling 100 gal/hr solvents.

$$100 \text{ gal} \times 16 \text{ hr} \times 22 \text{ days} = 35{,}200 \text{ gal/mo}$$

2 Hydrocarbon emission in automobile exhaust gases is estimated from the following data. Statistics from U. S. Department of Public Roads indicate 1958 passenger car registrations to be approximately 54 million. Corresponding gasoline consumption by these cars is reported at 51,864,631,000 gallons annually.

$$\frac{51{,}864{,}631{,}000}{54{,}000{,}000 \times 12} = 80.1 \text{ gal/car/mo}$$

Tests on hydrocarbons in exhaust gases from a representative group of cars operating in the Los Angeles area, has indicated that six percent of fuel used is discharged as unburned hydrocarbons. The average release is accordingly estimated at:

$$80.1 \times 0.06 = 4.8 \text{ gal/car/mo}$$

3 Comparison:

$$\frac{35{,}200}{4.8} = 7330$$ cars operating at average monthly rate are required to exhaust unburned hydrocarbons equivalent to the example oven.

Appendix B

Heat of combustion in solvent laden oven vapors and related temperatures available by catalytic oxidation.

G.P.H. Solvents per 1000 SCFM Exhaust when Btu/gal is			LEL, %	Latent Heat in Btu/1000 cu ft at 70°F Temp.	Temperature Rise from Catalysis, °F
80,000	100,000	120,000			
1.95	1.56	1.30	5	2,600	140
3.90	3.12	2.60	10	5,200	280
5.85	4.68	3.90	15	7,800	420
7.80	6.25	5.2	20	10,400	560
9.75	7.80	6.5	25	13,000	700
11.7	9.36	7.8	30	15,600	840
13.6	10.9	9.1	35	18,200	980
15.6	12.5	10.4	40	20,800	1120

First State Smog-Control Bill Controls Automobile Exhausts

The first state smog-control bill in history was passed recently by the California Legislature. Governor Edmund G. Brown signed it into law on April 13. It will control air pollution from automobile exhausts.

The legislation requires the installation of smog-control apparatus on all new automobiles sold in California a year after two such devices have been found to be acceptable.

The Bill was passed during a special session of the Legislation called by Governor Brown. S. Smith Griswold, chief of the Air Pollution Control District in Los Angeles, predicted that smog would disappear from Southern California within six years.

The provisions of the measure are that one year after approval, all used cars must be equipped with the devices except in counties that rule that they have no smog problem.

Two years after approval, all used commercial vehicles must have the smog reducers except in the exempt counties.

Three years after approval, all used cars must have the devices before they can be registered, again except in the exempt counties.

The counties that are excepted must make a smog survey every two years to prove that their situation has not changed.

The legislation provides for a 13-member motor vehicle board in the state Department of Public Health. It will include nine members appointed by the Governor, subjected to confirmation by the state Senate.

The other members will be the directors of the state Departments of Public Health and Agriculture, the Commissioner of the California Highway Patrol, and the Director of Motor Vehicles.

An appropriation of $500,000 was provided for the Department of Public Health in carrying out the provisions of the bill.

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Coal Sulfur Reduced In BCR Inc. Labs

Significant results leading toward the probable reduction of sulfur in bituminous coals have been achieved by Bituminous Coal Research, Inc., during fundamental research under cosponsorship of the electric utility and coal industries.

The announcement was made by J. A. Keeth, chairman of the Joint Research Advisory Committee. The program consists of a two-project program whose objective is the reduction of atmospheric contaminants in flue gases; it is sponsored by the Association of Edison Illuminating Companies and Edison Electric Institute jointly representing investor-owned electric utility companies and Bituminous Coal Research, Inc., for the coal industry.

Although financed by electric utility and coal industry money, the results of this project are expected to be of great financial significance to other industries —such as steel, chemical, general manufacturing—which burn coal or use it as a raw material in manufacturing.

Working with five high-sulfur bituminous coals from different areas of the United States, Bituminous Coal Research, Inc., has been able to liberate a substantial amount of the pyritic sulfur from the coal material. As a result, the Joint Research Advisory Committee and Bituminous Coal Research, Inc., have concluded that an effective process for reducing sulfur in bituminous coals is now possible.

WEST GERMAN SUBSIDIARY OPENS

Richard J. Ruff, President of Catalytic Combustion Corp., Detroit, Mich., announced recently the formation of a new European subsidiary, KAVAG (Katalytische Verbrennungsgesellschaft M.B.H.), with offices and factory located at Gondsroth-Hessen, West Germany.

Erwin C. Betz has been named Managing Director of KAVAG. Mr. Betz was born and educated in Germany, but has spent much of his professional life in the United States where he is a naturalized citizen. Prior to assuming his new duties, Mr. Betz was Plant Engineer for Catalytic Combustion.

The main offices of Catalytic Combustion Corp. are located in Detroit, with manufacturing facilities at Bloomer, Wis. The firm is a major producer of catalysts and systems for industrial fume elimination, and heat or power recovery. In the ten years since its introduction, the catalytic combustion process has become widely recognized for its ability to destroy noxious industrial odors and fumes and convert them to re-usable heat energy by low-temperature catalytic oxidation.

The new subsidiary will manufacture catalysts and catalytic combustion systems and perform related services for European customers under patent license from the parent company.

The formation of KAVAG now allows the extension to Europe of the techniques proved in the United States. In European countries, where fuels and electricity are scarce and costly, the value of recoverable heat energy is significantly higher than in the U. S.

Gas Washers Sold To Two Steel Plants

Two large steel producers have recently purchased Chemico Venturi Gas Washers for installation on their blast furnaces.

The Chemical Construction Corp., N. Y., has designed gas cleaning systems for Youngstown Sheet and Tube Co. at their Campbell Works in Youngstown, Ohio; and for the Inland Steel Co., Indiana Harbor Works.

When the Chemico washer is placed in operation for Youngstown Sheet and Tube, it will mark the 41st Venturi unit to be used for cleaning blast furnace gas by the industry. According to Chemico, the washer will be designed to clean gases to less than 0.05 gr of dust/scf.

DESIGN AND PERFORMANCE CHARACTERISTICS *of High-Velocity, High-Efficiency Air Cleaning* PRECIPITATORS*

HARRY J. WHITE, Director, and **WILLIAM H. COLE**, Physicist,
Research and Development Department, Research-Cottrell, Inc., Bound Brook, N. J.

The general objective of the work was the basic research and development of a high performance electrostatic air cleaning precipitator to operate at face air velocities in the range of 25 to 100 fps. The specific design and performance requirements included the removal of sub-micron air-borne dispersoids at efficiencies up to 99.8% in a precipitator of compact size and low ozone generation. These requirements are in sharp contrast to the performance characteristics of conventional air cleaning precipitators which normally operate in the velocity range of 6 to 8 fps with collection efficiencies of 90 to 95%.

The initial phase of the program was directed towards a specific application with the following target specifications.†

1. Collection efficiency = 99.8% on 0.7 micron oil fume based on penetrometer (light-scattering) measurements.
2. Air velocity = 2000 fpm based on the gross inlet cross section of the precipitator.
3. Maximum ozone generation = 0.10 ppm by volume.
4. Maximum draft loss = 1.0 in. wg.
5. Maximum precipitator length = 6.0 ft.

Theoretical Design Principles and Calculations

A study of the unusually rigid design and performance requirements clearly indicated the necessity for applying scientific design principles and equations rather than relying on empirical or intuitive approaches. Preliminary calculations indicated that a two-stage precipitator would provide the best solution to the problem of achieving a compromise between the mutually contradictory objectives of low ozone generation and high collection efficiency in a precipitator of compact size. Such a precipitator consists of a short particle-charging section followed by a longer corona-free particle collecting section. Although appreciable collection may occur in the charging section, it is designed with the primary objective of imparting a high percentage of particle saturation charge in the presence of minimum corona current and therefore minimum ozone generation. The collecting section which follows is designed with the objective of obtaining large collecting surface area and a maximum electric field strength in a non-discharging electrode system. However, it must be emphasized that these design objectives must be achieved at no sacrifice to the remaining fundamental requirement of good aerodynamic gas flow. Although precipitation theory normally assumes small scale turbulence, this requirement becomes increasingly important at the target air velocity of 2000 fpm.

The important design criteria established from the theoretical evaluation of the problem are summarized as follows:

1. A high level of particle charge in the presence of minimum corona current for a corresponding minimum ozone generation. This factor indicated the use of a short duct-type charging section with each duct consisting of one or more wires centered between two parallel plates to achieve minimum air velocity and maximum particle charging time. The current limitations further suggested the use of maximum duct width commensurate with a practical voltage level in the range of 35 kv. Such an arrangement results in a minimum length of discharge wire and corona current per unit cross section at a given average field strength.
2. Good aerodynamic gas flow and uniform gas distribution over the precipitator cross section were a basic requirement. These factors were essential for attaining optimum particle collection with no erosion of the collected material. The prevention of erosion is clearly required in a non-discharging collecting field since reentrained particles have no opportunity to be recharged for subsequent collection. The need for minimum disturbance of the inlet flow pattern was also a contributing factor in the selection of the flat plate ground electrodes in the charging section.
3. The complete elimination of gas sneakage around the electrode systems was essential for achieving 99.8% collection efficiency. This was accomplished in the very short charging section by top and bottom inlet baffles which insured total gas flow through the corona charging region before any expansion. However, gas sneakage becomes a more serious problem in the relatively long collecting section, and was partially responsible for the selection of a tube-type collecting electrode system. The arrangement consisted of a nest of small-diameter round tubes containing concentric high tension tubes. The high tension tubes were supported at each end by an aerodynamically designed high tension support frame. The ends of the outer collecting tubes were hexagonal in shape to provide compact stacking with a honeycomb inlet and outlet cross section for maintaining smooth gas flow, as compared to a nest of tubes fitted into a conventional header sheet.
4. The use of minimum diameter corona discharge wire commen-

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* Presented at the 52nd Annual Meeting of APCA, June 22–26, 1959, Statler Hotel, Los Angeles, Calif.
† This phase supported by the U.S. Bureau of Ships under Contract Nobs 54584.

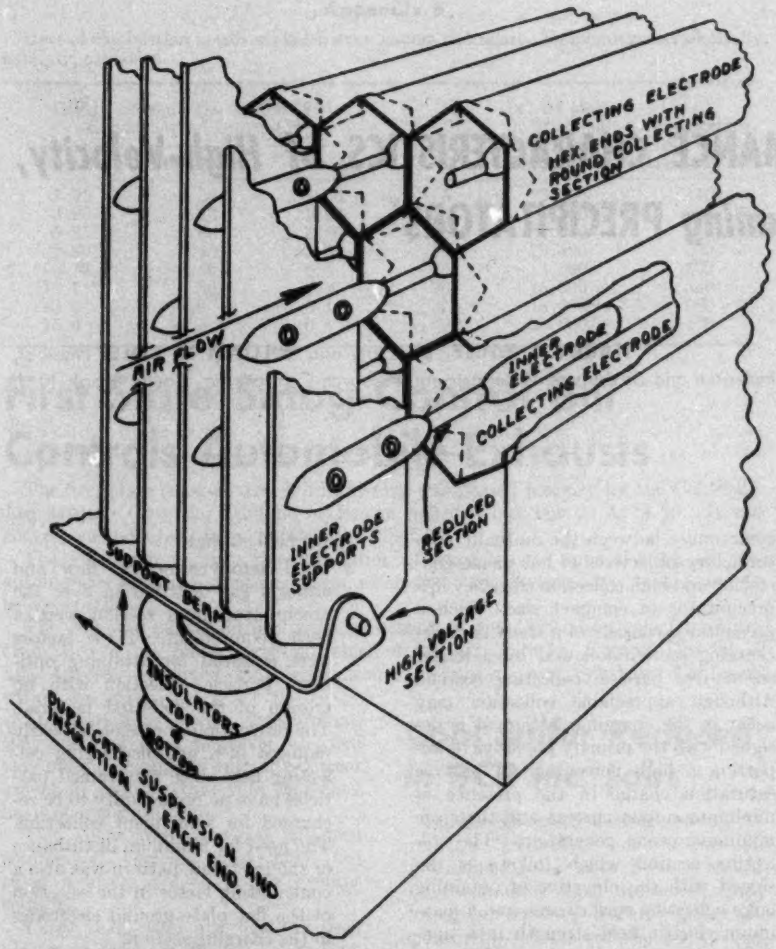

Fig. 1. Collecting section electrode and high tension frame assembly.

surate with adequate mechanical strength was indicated in order to minimize ozone generation in the charging section for a given corona current.

The initial approach in establishing the size parameters of an experimental unit was based on theoretical calculations applied to the following equation which governs precipitator efficiency.

$$E = 1 - e^{-(Aw/V)} \qquad (1)$$

The term w in equation (1) represents the velocity component of a particle in the direction of the collecting electrode due to the electrical forces. The theoretical expression of w is given by equation (2).

$$w = \frac{E_0 E_p a}{2\pi\eta} \cdot \frac{\gamma C}{30.4} \qquad (2)$$

It is of interest to note that the usual practice of determining the size (i.e., collecting surface area) of industrial precipitators for a required efficiency and gas flow, is to establish an empirical value for (w) in equation (1). This value is primarily based on a statistical study of w calculated from field measurements on precipitators previously installed for the same application. An empirical approach is necessary since w is normally a function of variable particle size distribution and electric field strength which usually cannot be predicted for a given industrial installation. Additional indeterminate factors include gas flow distribution and particle erosion which make it advisable to consider w as an empirical index of performance for a given application. In the case of a unique problem where direct experience is lacking, it is necessary to rely on theoretical principles. This approach is surprisingly reliable in the case of relatively small custom-made units where it is possible to exercise close control over gas flow and electrode tolerances and alignment.

The design of an experimental unit for the stated problem was based on an arbitrary inlet cross section of 1 sq ft and a design gas flow of 2000 cfm at the target velocity of 2000 fpm. A charging section collection efficiency of 40% was assumed on the basis of previous research work with particle charging sections in the specified gas velocity range. With this assumption, the required efficiency of the collector section was calculated to give an overall efficiency of 99.8%.

$$E_2 = \left(\frac{E - E_1}{1 - E_1}\right) = 0.9967 =$$

$$99.67\% \qquad (3)$$

Calculation of the required surface area for the collecting section for the given values of gas flow V and efficiency E_2 necessitated a theoretical calculation of w_2 from equation (2) (the subscript 2 refers to the collecting section parameters). The values for the average charging and collecting fields E_0 and E_p in equation (2) were estimated from previous experience with similar electrode geometries operating at stable voltage levels below sparking.

The assumed values of E_0 and E_p were:

$$E_0(\text{avg}) = 10 \text{ kv/cm} = 33 \text{ esu}$$
$$E_p(\text{avg}) = 15 \text{ kv/cm} = 50 \text{ esu}$$

The percentage of particle saturation charge (γ) was calculated for the particle charging time and an estimated charging section current density.

$$\gamma \text{ (estimated)} = 0.90$$

Replacing for E_0, E_p, a, η, and γ in equation (2) gives:

$$w_2 = \frac{(0.90)(33)(50)(0.35 \times 10^{-4})}{(6.28)(1.8 \times 10^{-4})} \times$$

$$\left(\frac{0.86 \times 10^{-6}}{0.35 \times 10^{-4}}\right) \times \frac{1}{30.4} = 1.90 \text{ fps}$$

Substituting the values of V, w_2, and E_2 in equation (1) and solving for A_2 gives a value of $A_2 = 100$ sq ft.

The maximum tube surface area for a given inlet cross section is obtained by using the smallest tube size commensurate with adequate concentric high tension tube diameter to prevent sag and permit accurate electrode alignment. It was determined that 1.5 in. O.D. thin wall collecting tubes and 0.5 in. O.D. concentric high tension tubes were in the range of the minimum practical size to give adequate annular electrode spacing of 0.5 in. and less than 0.01 in. sag per foot of high tension tube. A total of 68 collecting tubes were nested in the one-square foot cross section with a total surface area:

$$A_2 = 68\pi \frac{1.438L}{12} \text{ sq ft} \qquad (4)$$

For a required $A_2 = 100$ sq ft, $L = 3.9$ ft. For a maximum allowable length of 6.0 ft, a 10 in. long charging section and 4.0 ft collecting section allows a margin of 1.2 ft for high tension frame

supports and electrical clearances between sections.

These calculations completed the theoretical evaluation of the critical design principles and precipitator size parameters required to achieve the target performance.

Experimental Work and Correlation with Theoretical Design Calculations

The initial experimental unit designed on the basis of the foregoing theoretical evaluation, consisted of a 10-in. long charging section followed by a 4-ft long collector cell. The charging section comprised four plate-type ducts, of 3-in. spacing with each duct containing two 5 mil wires per duct. The 4-ft long collector cell comprised 68–1 1/2 in. O.D. nested brass tubes containing 1/2 in. concentric high tension tubes. The high tension support frame consisted of thin aerodynamic blades on the inlet and outlet of the collector cell resulting in an overall length of 6.0 ft to meet the target specifications. The charging and collecting sections were energized by separate dc power supplies to provide versatility of energization in the experimental phase of the work.

Performance tests were run on an oil fume aerosol of 0.7 micron average particle size determined in the course of Millikan oil-drop measurements of particle charge. Collection efficiencies were determined by a penetrometer supplied by the Naval Research Laboratory.* This instrument measures relative fume concentrations based upon light scattering of samples drawn continuously from the air stream. The instrument is therefore a continuous recording device, and efficiencies were normally determined by sampling at a fixed point in the outlet flue with the precipitator de-energized, followed by an instantaneous measurement upon applying energization. It was believed that this technique eliminated inaccuracies due to any uneven aerosol concentration which normally requires extensive flue traversing when efficiencies are determined from separate inlet and outlet measurements. Since the design basis for the instrument required uniform particle size, periodic particle size measurements were made and indicated consistent results with 90% of the fume between 0.65 and 0.75 microns. In addition to providing a very rapid measuring technique with low fume concentration (~1.0 milligram/cu ft), the instrument indicated excellent reproducibility of results and correlated well with check measurements of inlet and outlet weight samples.

Ozone measurements were made as a function of corona current and air flow using equipment developed and supplied by the Naval Research Laboratory. The basis of the technique was the chemical analysis of iodine liberation from a solution of potassium iodide. The experimental results indicated that ozone generation in parts per million was closely proportional to corona current and inversely proportional to gas flow rate for a constant corona wire diameter. Numerous measurements were made over a range of wire sizes as a separate phase of the program, and permitted subsequent calculation of ozone generation when evaluating other performance parameters.

The rapid measuring techniques permitted a large number of efficiency measurements over a complete range of variable gas flow and electrical energization. Although the performance is summarized in the curves of Figs. 2 to 4, the discussion will be limited to a direct comparison of the performance at the predicted theoretical design level, and also at a reduced charging current which satisfied the maximum allowable ozone concentration. The latter condition was obtained at a slightly higher voltage level by removing one of the two corona discharge wires in each duct. The data are summarized in Table I.

Table I—Performance Summary of the Initial 6 ft-Long Experimental Unit

	Target Specifications	Theoretical Design Ratings	—Measured Performance— At Effic. Ratings (2–5 Mil Wires/ Duct)	At 0.10 ppm Ozone (1–5 Mil Wires/ Duct)
Gas velocity (fpm)	2000	2000	2000	2000
Charging section voltage (kv)	—	38	38	40
Charging section current (ma)	—	—	20	12
Avg charging section field (kv/cm)	—	10	10	10
% Particle saturation charge	—	90	est. 95	est. 85
Ozone generation (ppm by vol)	0.10	—	0.15	0.10
Max collector voltage (kv)	—	18	15	15
Max avg collector field (kv/cm)	—	15	12.5	12.5
Charging section efficiency (%)	—	40	65	55
Collector section efficiency (%)	—	99.67	99.4	98.2
Overall efficiency	99.8	99.8	99.8	99.2
Coll. section precipitation w (fps)	—	1.90	1.66	1.30
Overall pressure drop (in. wg)	<1.0	<1.0	0.90	0.90

A review of the data presented in Table I indicates surprisingly good success in achieving the target specifications in the initial experimental unit. All performance requirements were attained with the exception of the ozone generation which was 50% above the target level. Of particular note is the good correlation of the collector section precipitation w's which in the case of the theoretical design value of 1.90 fps required calculated values for particle size and electric field strengths. It is interesting to note that the average collecting field achieved in the initial experimental unit was 12.5 kv/in. as compared to 15 kv/in. used in the design calculations. On this basis, the expected theoretical performance w from equation (2) is 1.90 x 12.5/15.0 = 1.58 fps which is in excellent agreement with the measured value of 1.66.

The overall collection efficiency at the reduced particle charging level and maximum allowable ozone generation of 0.10 ppm was 99.2%. Visual observation and measurement of the gas flow pattern indicated smooth gas flow and no erosion of the collected oil. It was therefore concluded that a large increase in the overall efficiency to 99.8% at the maximum ozone level, would require a fundamental improvement in performance rather than minor empirical improvements in design. The most profitable region for improvement appeared to be an increase in the collecting field strength which was invariably limited by sparking at the ends of the collector tubes. Such end effects are to be expected and are often eliminated in a single tube geometry by gradually flaring the outer tube ends. Although this cannot be done in a close packed nest of tubes, an alternative method is to taper the high tension electrode to a smaller diameter prior to the point at which it emerges from the collector tube. This presented a problem with hollow thin-walled electrodes which were required to minimize sag in a single 4-ft long collector. On this basis, it was necessary to fabricate the 1/2 in. diam high tension electrodes in three sections as shown in Fig. 1. The tubular center section extended to within 2 in. of the end of the outer collecting tube. Solid end pieces approximately 5 in. long were smoothly fitted to the hollow center section and were gradually machined down from 1/2 to 1/4 in. diam at the exit from the collector tube ends. This construction provided a firm cantilever support and aerodynamic electrode design at the gas entry to the collector cell. The electrode design change resulted in a significant 33% increase in collector cell voltage from 15 to 20 kv. This increase in the average collecting field

* "Development of Smoke Penetration Meters," NRL Report No. 2642 by H. W. Knudson and L. White, September, 1945.

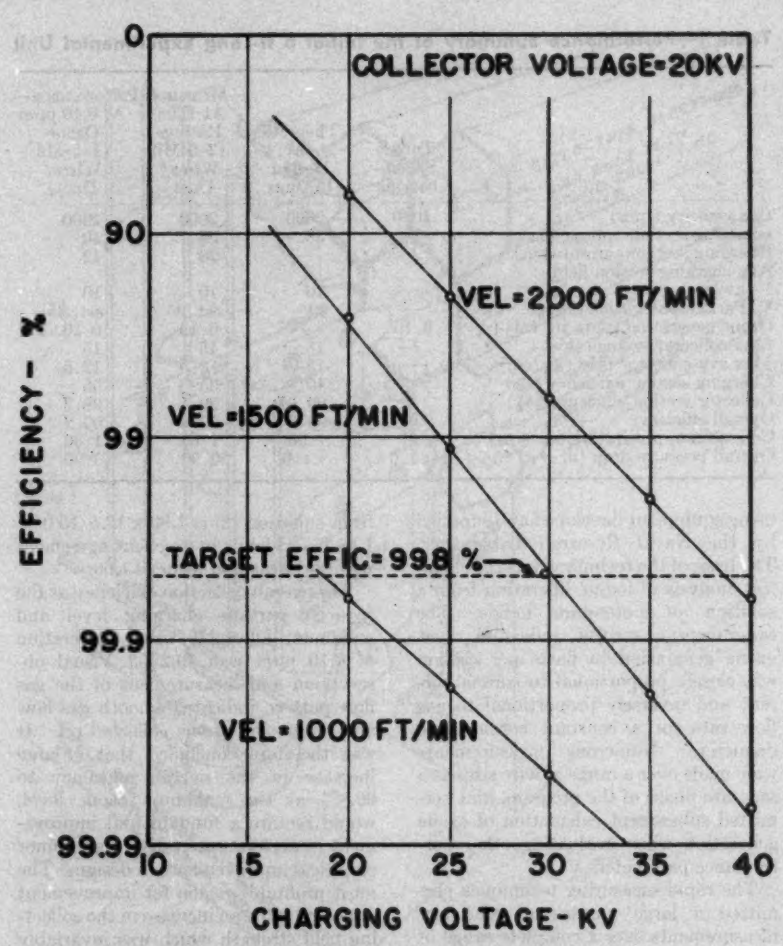

Fig. 2. Efficiency as a function of charging section voltage (experimental unit).

strength increased the overall collection efficiency at the target ozone level in Table I from 99.2 to 99.85%, thereby meeting every performance requirement of the stated problem and slightly surpassing the target efficiency. It is again of interest to note that a 33% increase in the collecting field and therefore the precipitation w in equation (2), would theoretically predict an increase in the collector cell efficiency from 98.2% to 99.55% to give an overall efficiency of 99.8%.

A final review of the experimental phase of the program did not indicate any additional areas for significant improvement based on theoretical principles. Therefore, the remainder of the program was devoted to attempts to surpass the target requirement by design changes of an intuitive nature. This included attempts to reduce ozone generation and permit higher charging voltages by the use of various type discharge electrodes, and a re-design of the collector cell high tension frame support. Discharge electrodes tested included various size ribbon electrodes, short prong type wires supported by an appropriate high tension frame in the gas stream, and various wire diameters in the conventional duct geometry. In the case of the high tension frame design changes, overall performance greatly deteriorated from 99.85% to the mid 90% range. The causes were clearly apparent from visual observation of reentrainment of the collected oil fume resulting from gas turbulence caused by the inferior high tension frame designs. Of the eight discharge electrodes tested, all resulted in increased ozone generation often accompanied by a decrease in collection efficiency. However, the use of 7 mil wires were incorporated in the final experimental unit to give a safety margin of dependability against breakage during shock tests which were also included as a performance specification. The use of 7 mil wires increased the ozone generation by 15% at the charging section performance level of 40 kv, 12 ma. This was offset by decreasing the voltage-current level to 38 kv at 9.5 ma to retain an ozone generation of 0.10 ppm. The effect of reduced charging voltage on the collection efficiency was a decrease from 99.85% to the exact target value of 99.80%.

Prototype Design and Performance Criteria

At the successful completion of the experimental program, it was required to design and construct a prototype unit based upon a revised set of final specifications. A photograph of the overall prototype unit is shown in Fig. 5.

The altered design requirements were as follows:

1. Reduction in overall precipitator length from 6 to 4½ ft.
2. Addition of automatic hot water cleaning sprays preceding the precipitator. These sprays also served as a means of applying an adhesive film to the collecting electrodes following cleaning.
3. Design of right angle transition sections containing turning vanes to be installed at the precipitator inlet and outlet to provide smooth gas flow for vertical precipitator installation with horizontal inlet and outlet flues. Overall height, including vane transitions, was not to exceed 7 ft.

The major reduction in precipitator length was achieved by reducing the collecting tube length from 4 to 3 ft. The additional 6 in. was obtained by reducing the charging duct length from 10 to 6 in. and a general tightening up of electrical clearances. The effect of reducing the collecting cell length by 25% was obviously reflected by a decrease in collecting performance. In order to maintain the design efficiency, it was necessary to make a corresponding reduction in precipitator gas flow so that in the equation of precipitator efficiency, the quantity A/V for the collector cell remained constant. The revised target values were thus changed to 99.8% collection at a gas velocity of 1500 fpm. As expected, the ozone generation in ppm by volume increased 25% due to the reduced gas flow. This factor was offset by increased treatment time and increased particle charging in the charging section at the reduced velocity, which permitted a decrease in voltage and current in the charging section from 38 kv-9.5 ma to 35 kv-7.6 ma. This maintains a constant corona current per unit gas flow and therefore constant ozone generation of 0.10 ppm by volume. The performance of the prototype as a function of ozone concentration is shown in Fig. 6. The performance values achieved by the prototype unit at the target level of 0.10 ppm are summarized as follows:

Efficiency	99.8%
Gas velocity	1500 fpm
Ozone generation	0.10 ppm by vol
Pressure drop	0.40 in. wg
Overall precipitator length	4½ ft (excluding turning vane transitions

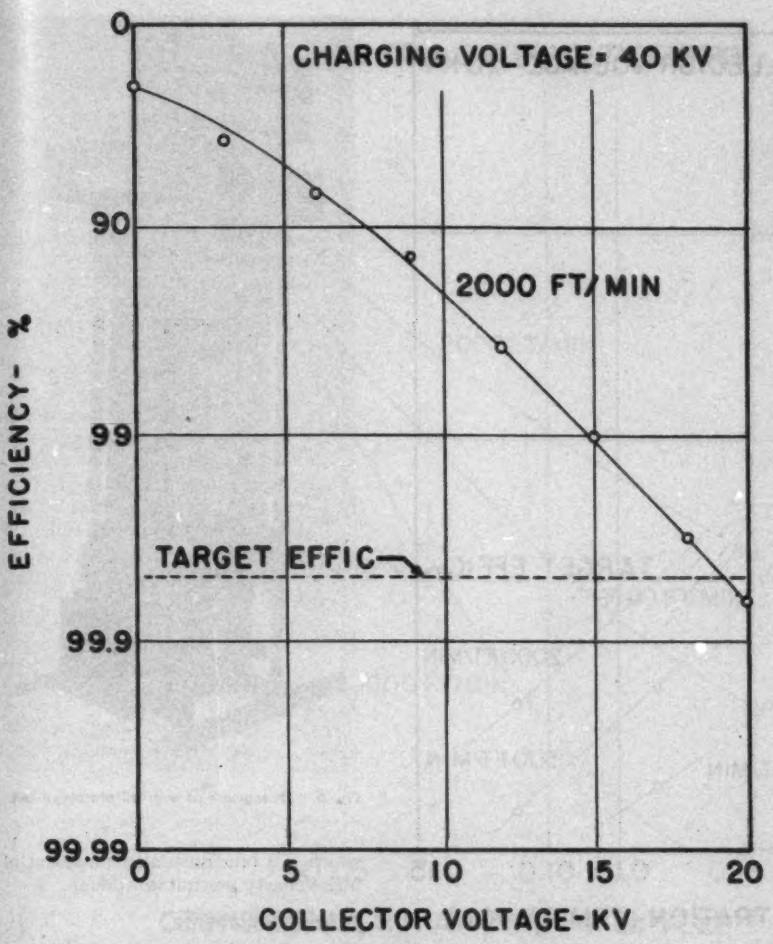

Fig. 3. Efficiency as a function of collecting section voltage (experimental unit).

At the completion of the laboratory work on the prototype design, the unit was placed in service by the Bureau of Ships for evaluation of the reliability and level of performance during four months continuous operation. Electrical readings were taken daily in order to determine a practical cleaning cycle that would permit an optimum level of energization. It was reported that the precipitator maintained the target performance during the entire period with no failure whatever of the equipment. It was also determined that a practical cleaning cycle of four weeks was required to maintain the design voltage levels without excessive sparking (less than 10/hr), and that full energization could be applied within several minutes after the automatic hot water cleaning.

Full-Scale Unit

The independent performance evaluation of the 1500 cfm prototype unit led to a request for the design and construction of a full-scale unit having a gas flow rating of 8600 cfm at 99.8% collection efficiency.

The successful performance of the prototype resulted in a specification that the full-scale unit be an exact scaled-up version of the prototype with no suggestions for any design improvements. The full-scale unit was placed in operation with the experimental and prototype models with no failure of the equipment.

Extension of Work to Treatment Velocity of 100 fps

An extension of the basic research on air cleaning precipitators was made in the ultra-high velocity range of 100 fps. The objective of this work was to determine the feasibility of utilizing air cleaning precipitators for the removal of small quantities of oil fume from high velocity wind tunnel air streams. The oil fume originated at infrequent intervals as a result of compressor gasket failures. The slightest oil film deposited on a test model surface prevented accurate evaluation of shock wave patterns, and required costly shutdown and cleaning of the entire venturi test section. It was concluded that electrical precipitators might provide a practical solution to the problem which required small compact equipment that would not add significantly to the volume of the wind tunnel system.

The initial theoretical evaluation of the problem indicated the use of a single-stage duct-type precipitator, since the original target specifications placed no limitations on ozone generation. In such cases, the single-stage design normally provides higher collection efficiencies and smaller erosion losses than the two-stage type. It was evident that the principal design problem was the need for aerodynamic gas flow, and a means for preventing re-entrainment of the collected oil fume. The duct-type precipitator with high tension frame systems out of the gas stream results in minimum gas flow disturbances and is more amenable to various type baffling arrangements for minimizing re-entrainment. The single-stage unit designed and tested in the laboratory, consisted of two 3-in. ducts, 14 in. high by 9 ft long with each duct containing twenty 18 mil corona discharge wires. It was determined that an important factor in the flat collecting plate design was the elimination of streamline terminations at the trailing edge of the collecting plates. Although good aerodynamic gas flow and the high current density prevented the onset of erosion at gas velocities up to 100 fps, it was established that velocities of 150 fps could be attained without erosion by the use of slotted tube baffles on the trailing edge of the collector plates as shown in Fig. 7. The collected oil flowed along the plate surface to the trailing edge, and drained into a sump not contained in the gas stream. The slotted tubes made no contact with the collecting plates, and provided a shielded region of low turbulence which prevented blow-off normally encountered with streamline trailing edges.

During the initial investigation of single-stage precipitation, concurrent studies indicated that ozone concentration was indeed an important factor in the solution of the problem. This was evidenced by deterioration of certain rubber components in the wind tunnel system which could not be conveniently eliminated. On this basis, the work was extended to studies of a two-stage design which consisted of the original single-stage unit with the final 15 of the 20 discharge wires per duct removed in favor of flat-plate non-discharging high tension electrodes. Although there was a decrease in collection efficiency with the two-stage unit, no difficulty was experienced with re-entrainment. The ozone concentration was kept to a suitable limit, and there was a significant decrease in corona power requirements.

The performance data for both the single and two-stage units are sum-

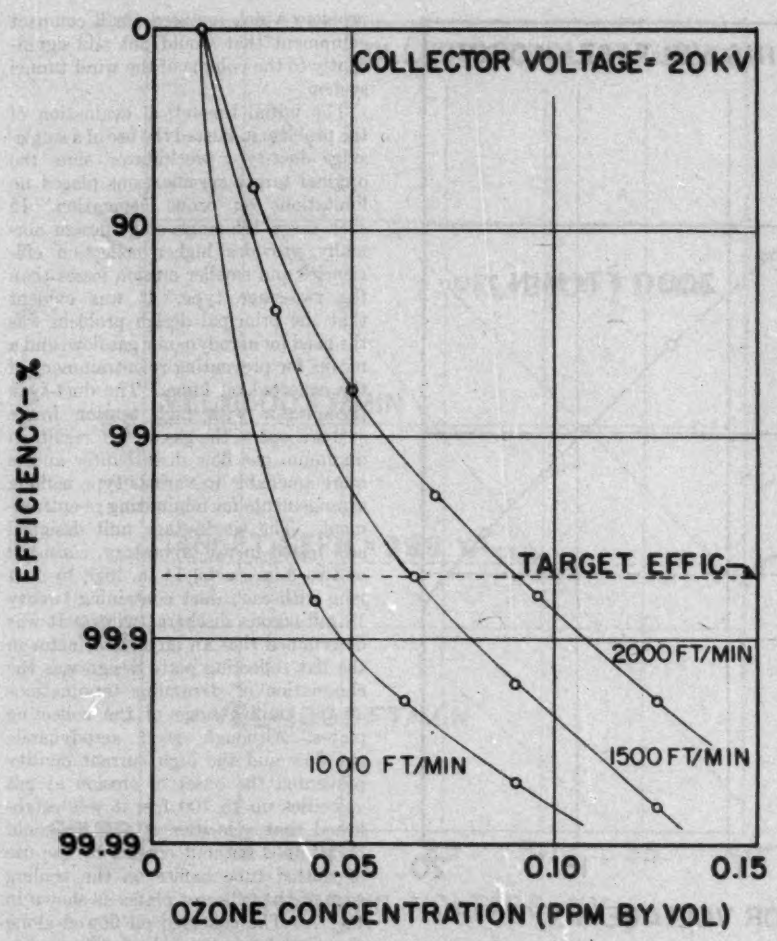

Fig. 4. Efficiency as a function of ozone generation (experimental unit).

marized in Table II. Although the corresponding theoretical design calculations are not given for this problem, it is important to note that such calculations were made based on equations (1) and (2). In all cases, the theoretical calculations were found to be in good agreement with the performance values, with less than 15% discrepancy between the experimental and calculated precipitation w.

Conclusion

The application of scientific design principles and equations has provided a successful approach to the development of high-velocity high-efficiency air cleaning precipitators. Efficiencies of 99.8%+ have been achieved in both the laboratory and on a full-scale installation at gas velocities of 25 to 35 fps, with ozone generation limited to 0.10 ppm by vol. The feasibility of applying two-stage electrostatic precipitation to air cleaning problems at velocities as high as 100 fps has been demonstrated on a laboratory scale with an oil fume aerosol. Reentrainment has been effectively prevented by the application of aerodynamic principles which is a fundamental requirement of high-velocity precipitator design.

Table II—Performance Summary of Single and Two-Stage Duct Precipitators with Equal Collecting Surface Areas

	Single-Stage Unit		Two-Stage Unit	
Gas Velocity	100 fps	50 fps	100 fps	50 fps
Collection efficiency (%)	91	98	80	96
Corona current (ma)	121	121	27	27
Corona power[a] (KW)	4.8	4.8	1.2	1.2
Ozone concentration (ppm by vol)	est. 1.43	est. 3.05	0.32	0.68
Pressure drop (in. wg)	2.65	0.80	2.80	0.84

[a] Negative polarity—dc energization.

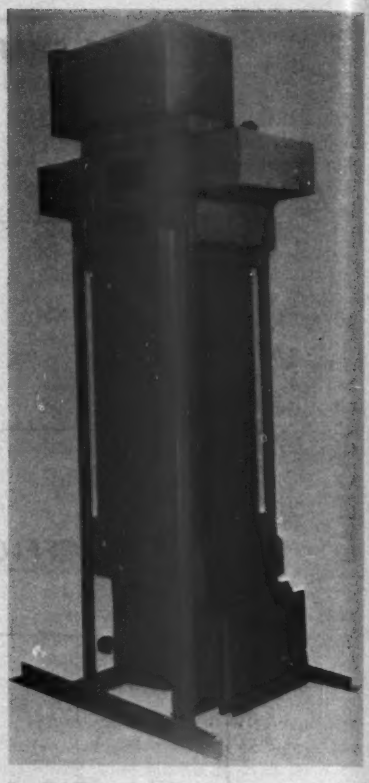

Fig. 5. Photograph of over-all prototype unit.

Acknowledgments

The authors wish to express their gratitude to A. E. DeSomma of the Bureau of Ships and Dr. J. A. Young of the Naval Research Laboratory for their co-operation and advice throughout the project. Acknowledgment is made to J. A. Armstrong of Research-Cottrell, Inc. for contributions in the design work, and to W. A. Baxter of Research-Cottrell, Inc. for the extensive experimental work and assistance in analysis of the data.

Nomenclature

E = Fractional precipitator collection efficiency
A = Precipitator collecting surface area in sq ft
V = Gas flow in cu fps
L = Collecting section tube length in ft
w = Precipitation drift velocity in fps
γ = Fractional particle saturation charge
E_0 = Average charging field strength in statvolts/cm
E_p = Average collecting field strength in statvolts/cm
a = Particle radius in cm
η = Air viscosity in poises

$$C = 1 + \frac{0.86 \times 10^{-5}}{a}$$

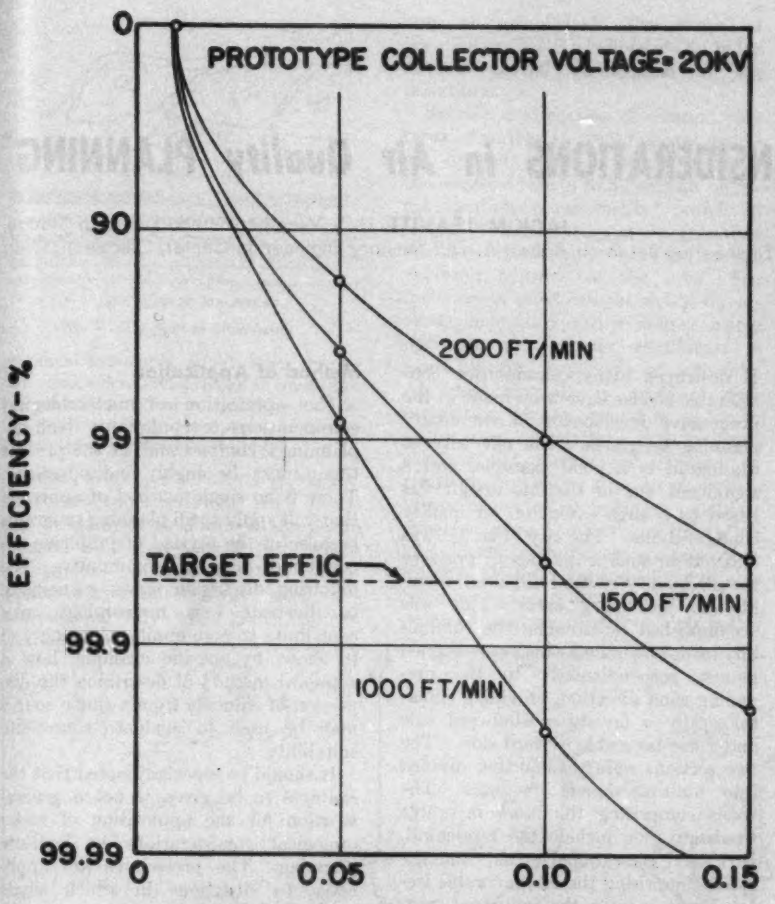

Fig. 6. Prototype efficiency as a function of ozone concentration.

Cunningham correction factor for Stokes' Law where particle size is comparable to the mean free molecular path.

Subscripts

E_1, A_1, w_1 denotes charging section parameters

E_2, A_2, w_2 denotes collecting section parameters

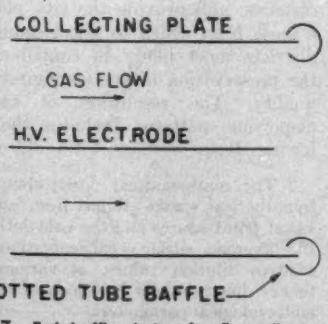

Fig. 7. End baffle design for flat collecting plates.

Research Provides New Technique

A new technique, researched by the Los Angeles Air Pollution Control District and the Engineering Department of the University of California at Los Angeles, reduces the oxides of nitrogen in auto exhaust by 80 to 90%.

A small amount of cooled exhaust gas is introduced into the engine intake system by means of a tailpipe-to-carburetor, tube and valve device costing less than $15. Other smog formers must still be controlled by afterburners or other devices. Benefits of the method: reduces engine knock, lessens the need for antiknock compounds in gasoline, permits high-compression engines to operate on lower-cost, lower-octane gasoline. There is no uncorrectable power loss in the engine, nor increase in unburned hydrocarbons in the exhaust.

Why the nitrogen oxides are reduced by this method is not clear as yet, although it is believed that the exhaust gas dilutes the oxygen content of intake air, thus lowers the temperature.

APCA Honors Three Members At Annual Meet

Robert A. Kehoe Thomas C. Wurts

William A. Hamor

♦ ♦ ♦

APCA honors three of its members: Dr. Robert A. Kehoe, Thomas C. Wurts, and Dr. W. A. Hamor.

Dr. Kehoe is the recipient of the Richard B. Mellon Award for his contributions to the knowledge of the effect of atmospheric contaminants on human life, for his research in helping mankind to better cope with his environment; and his generosity in giving of his time and experience to further local air pollution efforts.

He is a founder and director of the Kettering Laboratory. His guidance and counsel have been sought by numerous industries and governmental officials.

* * *

Dr. Hamor and Mr. Wurts have been named honorary members of the Association. Dr. Hamor is retired advisor to the APCA Fellowship at Mellon Institute and former senior Director of Research.

Mr. Wurts, past president of the Association and past member of the Board of Directors, served with Westinghouse Electric Corporation in Sales Engineering and Manager of Heavy Traction Sales before establishing his own office as consulting engineer. He was also Director of the Allegheny County Smoke Control Bureau from 1947 to 1959.

APCA extends its congratulations to all three of these gentlemen, and thanks them for their contributions to the cause.

METEOROLOGICAL CONSIDERATIONS *in Air Quality* PLANNING*

JACK M. LEAVITT, U. S. Weather Bureau Research Station,
Air Pollution Engineering Research, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

City planners are now turning to land-use programs, especially for locating industrial areas, to eliminate potential community air pollution problems. This land-use approach is particularly applicable to progressive community growth as it furnishes opportunity for co-ordinated expansion of industrial, commercial, and residential development, while at the same time it provides industrial areas strategically located so that their pollutant emissions will have little harmful effect on the community. However, the application of air quality features to land-use industrial planning is a relatively new study and involves many related considerations which have not yet been resolved into workable criteria. For instance, further study of the turbulent nature of the urban atmosphere and the atmospheric effects on effluents, *e.g.*, solar radiation and precipitation washout, is required before the transport and dispersion characteristics of pollutants can be objectively used in determining probable dispersion patterns of air contaminants from known sources. From such patterns, the contribution of various source emissions to pollutant levels at various points in the community can be analyzed, thus providing the city planner, in some circumstances, an additional criterion for the selection of areas for industrial development which would contribute minimum atmospheric contamination to the community.

Cannot Be Ignored

It is appreciated, of course, that the relative importance of meteorological considerations can, in principle, be reduced to negligible proportions by appropriate control measures at the sources of emission. In many cases the economic balance sheet will unquestionably show control at the site to be the proper course of action; but in drawing up this balance sheet, the meteorological factors should not be ignored.

In Europe, where World Wars I and II destroyed many communities, considerable strides have been made in the progressive development of community planning programs. The new city of Stalingrad is a good example, and a significant one in that its design was based to a large extent on air quality considerations. The city (Fig. 1)[1] was laid out in such a manner to preserve the air quality of the residential, recreational, and park areas. This was accomplished by dividing the community into two sections which were aligned almost perpendicularly to the prevailing wind direction, providing climatologically a favorable windward side and a less favorable leeward side. The two sections were then further divided into multiple bands or zones. The zones comprising the more favorable windward side include the residential, park, and recreational areas; and the zones comprising the less favorable leeward side include the industrial, railroad, and green-belt highway areas. With this type of zoning the prevailing wind first passes over the park and recreational areas, then over the residential areas, and then over the green-belt area which conceals the main highway from the city (located to the right off the figure) and separates the residential area from the industrial and railroad areas. Thus, it is possible to maintain good air quality in the residential area and yet the homes are but a few miles removed from the major pollution sources in the industrial zone.

Communities in this country have been spared the devastation of war, and consequently have had limited occasion to undertake large-scale urban redevelopment programs. The Stalingrad plan probably would not apply widely in this country where the annual wind distribution in most cities is too variable to base a city layout on prevailing wind direction. Likewise the economical, social, and other considerations involved in urban design are of higher priority in most cities than those relating to air quality. Urban planning in this country would therefore require a more sophisticated treatment of air quality features than in the case of Stalingrad where wind direction alone was the dominant design criterion.

Method of Application

The application of meteorological considerations to community land-use planning is complex and, at the present time, must be highly individualized. There is no single method of approach that will apply to all planning programs because of the myriad of problems encountered in each community. The following discussion serves principally to illustrate how meteorology may contribute to community planning and to show, by specific example, how a standard method of describing the dispersion of effluents from a single source may be used to evaluate source-site suitability.

It should be especially noted that the example to be given is not a general solution for the application of meteorological considerations to land-use planning. The procedures are applicable to situations in which single values of the meteorological parameters, such as wind speed and direction, exist and can be ascribed for the entire area of interest. Specifically, the case of calm or very light and variable winds is not treated, but rather one in which the air flow and weather conditions might be said to be as normally experienced from day to day or week to week.

The method of application consists of two phases. The first involves quantitative estimates of pollution distribution patterns from proposed districts marked for industrial development. Such patterns provide an index of the relative pollution contributions to the community from the various districts, and provide the city planner a basis from which to select industrial districts most likely to contribute to the preservation of the community air quality. The resolution of specific dispersion patterns includes the following steps:

1 The mathematical description of a hypothetical smoke plume from an elevated point source and the calculation of the average surface concentrations, or relative dilution values, at various distances downwind as functions of certain meteorological parameters.

2 The modification of pollution distribution patterns where local physio-

* Presented at the 52nd Annual Meeting of APCA, June 22–26, 1959, Statler Hotel, Los Angeles, Calif.

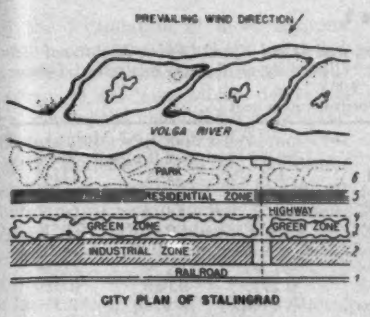

Fig. 1. City plan of Stalingrad.

graphical influences might alter the air flow, and where meteorological conditions are such that diffusion equations used in the mathematical description of smoke plume behavior would not apply.

Dilution values obtained in step *1* above are combined with wind direction frequencies to obtain a composite dilution wind rose pattern from which estimates of potential pollution contribution within an arbitrary area, circumscribing any one given source, may be established. The shape of the dilution pattern represents an index of the spatial distribution of the pollutants.

Specific modification of dilution patterns, described in step *2* above, generally depends upon the degree to which the source districts fulfill certain physical location requirements,[2] which in terms of meteorological-topographical standards relate primarily to the natural exposure features of the area. For instance, in most cases it would be advantageous to locate a source where optimum atmospheric ventilation is available for dispersion of effluents. An ideal example, in areas of high population density, would be to locate source areas on relatively high and well exposed flat terrain, as opposed to relatively low valley type areas, since a higher degree of air pollution might be expected more frequently in the valley areas during certain meteorological conditions. Valley source areas might also be more undesirable from the standpoint of creating relatively high pollution levels at points where elevated plumes intersect higher terrain surrounding the valley. On the other hand, valley sites of low population density may prove advantageous for channeling or deflecting pollution away from community areas located on high level terrain adjacent to the valley. Obviously then, there is no single set of meteorological and topographical location requirements which apply to all industrial siting problems. Such location requirements must therefore be flexible enough to be used with other forms of location standards for selecting industrial districts which will benefit the health, economy, and the general amenities of urban living. Many of the physiographical influences which cause spatial irregularities in community air flow have been described elsewhere.[3]

The second phase in the application of air quality considerations to industrial land-use planning involves the evaluation of source-site suitability in terms of the functional characteristics of the

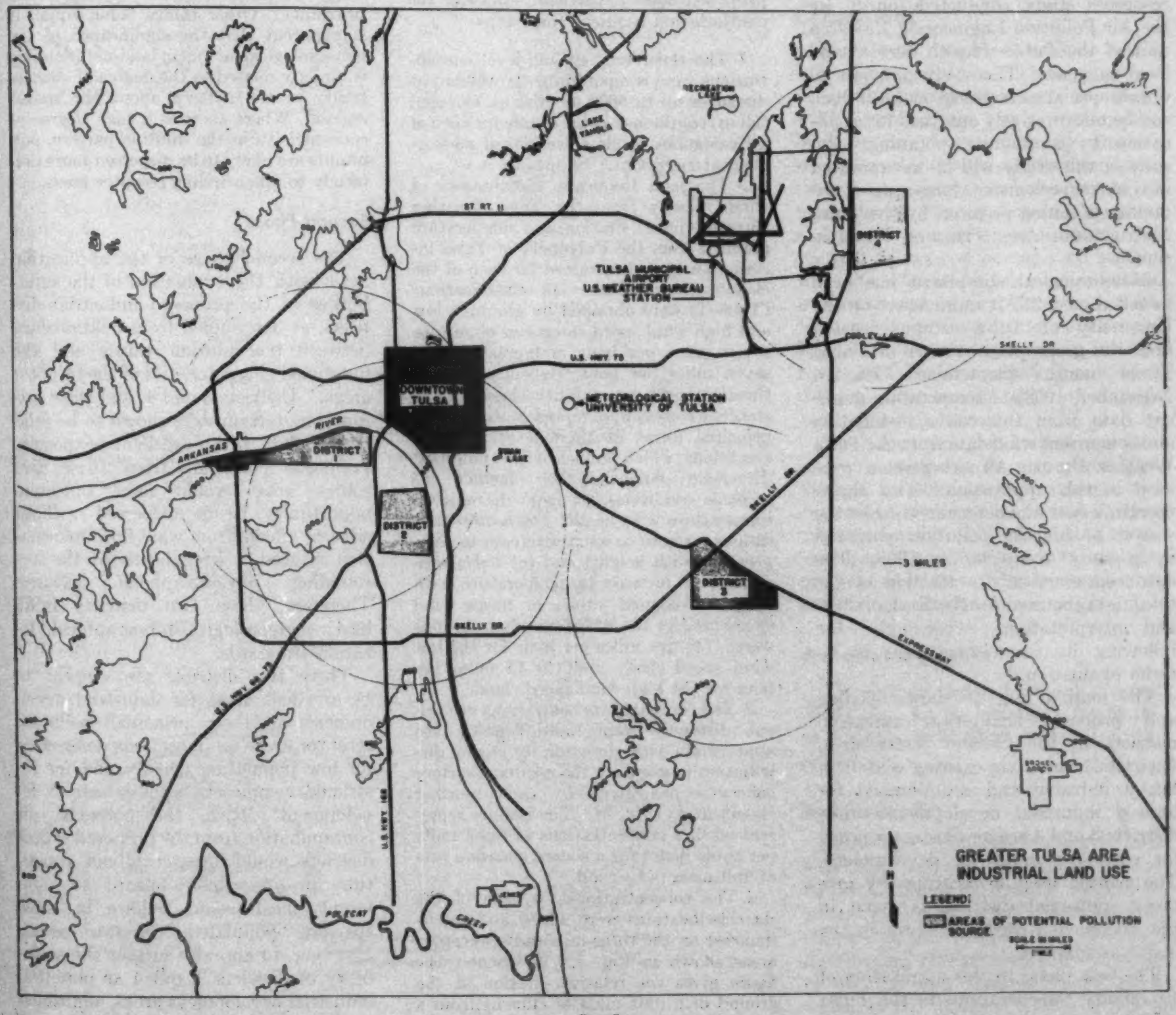

Fig. 2.

receptor areas, as defined in master plan objectives, and the potential pollution contribution to the receptor areas from the various source sites in terms of the respective dilution patterns. For instance, whether a receptor area is designated for residential, for recreational, or for commercial development, the tolerable thresholds of atmospheric pollution within that receptor area for each use would be of prime concern to the city planner. In case the threshold values were exceeded, perhaps one or more of the proposed source areas which contribute to the atmospheric contamination of the receptor area would have to be eliminated as prospective industrial sites. Again, decisions of this type are highly subjective and should be based on the cooperation and technical skills of the city planner, the air pollution engineer, and the meteorologist.

Table I

Joint Frequency Distribution of Wind Direction and Wind Speed (Tulsa Municipal Airport), and Vertical Temperature Difference, γ[a] (University of Tulsa), September, October, November, 1958.
See Appendix A for definitions of n and C_z.

	Wind Speed 0–7 Mph ($\bar{u}$ = 2.3 mps)			Wind Speed >7 Mph ($\bar{u}$ = 6.0 mps)		
	I	II	III	I-A	II-A	III-A
	Unstable ($\gamma \leq -1.0$°F), n = 0.20, C_z = 0.306,	Neutral (-1.0°F < γ 0.0°F), n = 0.25, C_z = 0.102,	Stable ($\gamma \geq$ 0.0°F), n = 0.33, C_z = 0.035,	Unstable ($\gamma \leq -1.0$°F), n = 0.20, C_z = 0.277,	Neutral (-1.0°F < $\gamma <$ 0.0°F), n = 0.25, C_z = 0.089,	Stable ($\gamma \geq$ 0.0°F), n = 0.33, C_z = 0.029,
Wind Direction	% Freq.	% Freq.	% Freq.	% Freq.	% Freq.	% Freq.
N	2.7	1.3	4.6	8.1	1.0	0.7
NE	0.9	0.1	0.1	2.1	0.0	0.0
E	0.9	0.2	0.9	0.6	0.0	0.0
SE	6.6	2.8	3.3	1.9	0.2	0.0
S	8.8	3.3	5.5	20.7	1.6	1.2
SW	2.4	0.4	1.4	1.4	0.1	0.2
W	0.5	0.2	0.1	0.7	0.0	0.1
NW	1.4	0.4	1.5	0.5	0.0	0.1
Calm	3.4	0.6	4.5	0.0	0.0	0.0
Total	27.6	9.3	21.9	36.0	2.9	2.3

[a] γ = temperature difference °F (212 ft-25 ft).

Example of Method

Tulsa, Oklahoma, is the site of an air resources study conducted jointly by the Air Pollution Engineering Research unit of the Public Health Service and local agencies. The study proposes to obtain special meteorological data which can be interpretively analyzed for application to community planning. Results of this study will be incorporated into a comprehensive, long-range community planning program by the Tulsa Metropolitan Area Planning Commission.

Meteorological equipment has been installed on a 215-ft radio tower on the University of Tulsa campus located near the geographical center of Tulsa. Three months (September, October, November, 1958) of temperature gradient data from this tower installation and concurrent wind data from the Tulsa Weather Bureau Airport Station were used in this application. This three-month period was determined to be the season of highest pollution potential by a study[4] completed in 1958. The data represent only a fraction of the total data required for the final analysis and interpretation. Accordingly, the following discussion constitutes an interim evaluation.

The map in Fig. 2[5] shows existing and proposed heavy-type industrial districts in the Greater Tulsa area. Districts 1 and 2 are existing centers of heavy industry and are planned for limited industrial development, while districts 3 and 4 are new areas proposed for extensive industrial development. The criteria used in locating the proposed industrial districts is given in the Technical Report[6] from which the map was adapted.

The first phase in this application of air quality considerations to the Tulsa industrial land-use planning program involved the computation of relative pollution concentration patterns for the proposed source districts. Briefly, the computation required four steps:

1 The theoretical ground-level concentrations were computed for the effluent at distances up to 5000 m from an elevated (50 m) continuous point source for each of six categories or classifications of meteorological conditions. (Appendix A.)

2 The joint frequency distributions of wind velocity from the Tulsa Weather Bureau Airport Station and temperature gradient from the University of Tulsa installation were determined for each of the classifications. These six classifications (Table I) were obtained by grouping low and high wind speed categories of zero to seven miles per hour and greater than seven miles per hour, respectively, into three atmospheric stability classes. The stability classes were representative of the principal forms of thermal atmospheric conditions which influence the pollution dispersion potential; they include: (*a*) *unstable* conditions, or large decrease in temperature with height; (*b*) *neutral* conditions, or zero to small decrease in temperature with height; and (*c*) *stable* conditions, or increase in temperature with height. Assigned values of mean wind speed used in the diffusion computations were: (*a*) five miles per hour for the low wind speed class; and (*b*) 13 miles per hour for the high wind speed class.

3 The computed concentrations at various distances were multiplied by the appropriate wind direction frequency distribution to establish the resultant surface concentrations given by each weather classification (Fig. 3). The isolines represent surface concentrations in mass units per cubic meter for a source emission rate of unit mass per second.

4 The concentrations for each of the six classifications were added and superimposed on the three-mile radial receptor areas shown in Fig. 4. In essence, the figure gives the relative dilution at the ground of a unit mass of effluent from a source in each of the four districts during the three months of concern. Note: Dilution patterns for source districts 1 and 2 were combined because of their close proximity. Other things being equal, it is apparent that the significance of the meteorological factors in land-use planning is directly related to the degree of concentricity of the pattern about the source region. Where there is a high degree of concentricity in the dilution pattern, pollutants are likely to be dispersed more uniformly to all encircling receptor areas.

Second Phase

The second phase of the application deals with the evaluation of the suitabilities of the proposed industrial districts, as determined from relationships between the dilution values and the functional characteristics of the receptor areas. Districts 3 and 4, and their surrounding terrain were shown to be relatively flat with excellent exposure. Pollutant emissions from these two source areas would have optimum opportunity to be dispersed without adverse effects from wind flow deformation induced by irregularities in the surrounding physiographical features. Therefore, these two districts fulfill basic meteorological-topographical location standards.

These two districts also appear to be excellent areas for industrial development as their principal pollution receptor areas lie in sections designated for low population density and for restricted commercial and industrial development. Thus, the potential air contamination from the proposed source districts would apparently not constitute an appreciable hazard to community health and welfare in these sparsely populated receptor areas. However, to appraise further the suitability of districts 3 and 4 as potential industrial development areas, additional studies would be required relating to:

(a) the formulation of more rigorous dilution patterns based on detailed investigation of the micrometeorological features of the area which determine the dispersion characteristics of the effluents under various kinds of meteorological conditions; and (b) the establishment of tolerable levels of the air contaminants on humans, animals, plants, and other objects within the receptor area. Once such information is available through the advancement of meteorological and epidemiological research in air pollution, the city planners would be able to formulate improved industrial planning performance standards which would enable pollution levels to be maintained within tolerable limits established for the receptor area.

The suitability of districts 1 and 2 for further industrial development is problematical. While most of the Greater Tulsa area is relatively flat, there are marked topographical irregularities in the peripheral areas adjacent to these two industrial districts. Within an approximate three-mile radius there are rises in elevation of about 400 ft to the north and northwest, 300 ft to the southwest, and 100 to 200 ft to the east of the river. After preliminary consideration, it would appear that districts 1 and 2 would not conform as well to basic meteorological-topographical standards for industrial development. The two districts occupy a portion of a shallow river flood-plain where relatively high levels of atmospheric pollution might develop, especially within the vicinity of the principal emission sources, during extended periods of light winds and stable temperature stratification. Possibly this industrial pollution would be further supplemented by drainage and channeling of contaminated air into the shallow valley from adjacent pollution sources.

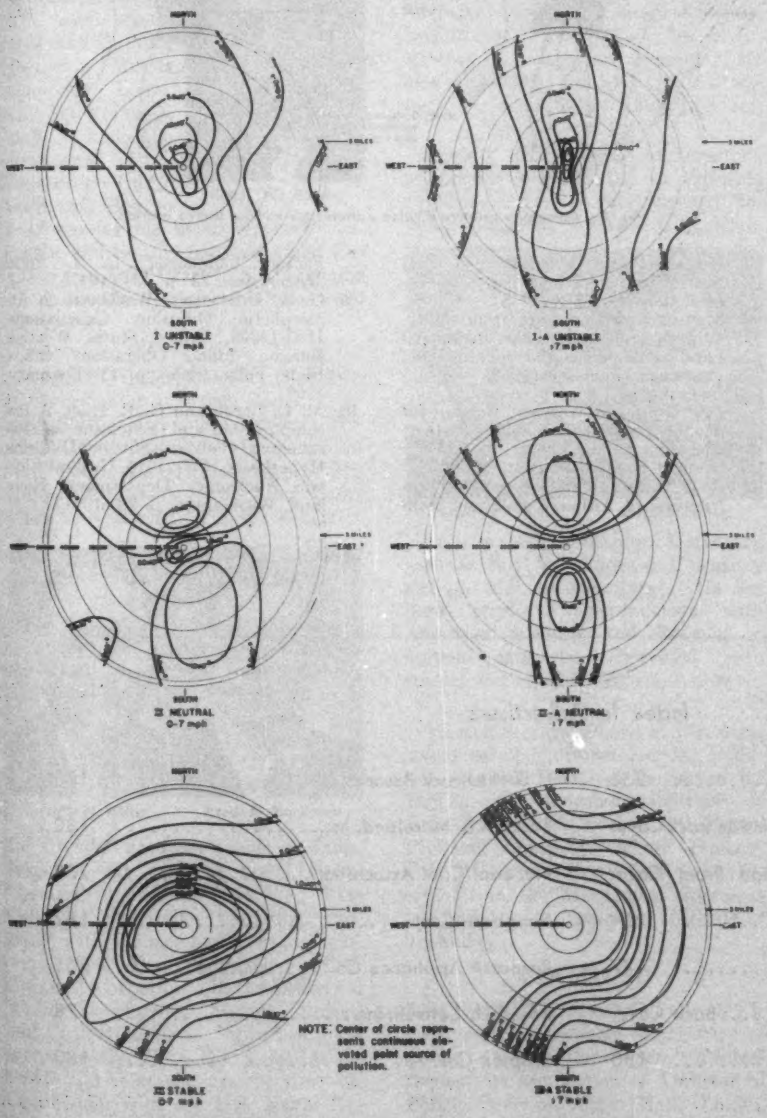

Fig. 3. Relative dilution patterns for various weather classifications.

The principal receptor areas for districts 1 ond 2 indicate that relatively high pollution potential could be expected in the hilly region to the north where extensive residential development is anticipated and in the metropolitan downtown district to the northeast. Detailed modifications of the dilution pattern would probably be required for a full analysis of the situation, as there are probably marked physiographical effects on the air movement in this localized area.

It should be added that the receptor areas of source districts 3 and 4 may have higher tolerable levels of atmospheric contaminants than the receptor areas of source districts 1 and 2 because of their different functional characteristics. This is a further indication that performance standard requirements for the corresponding source districts would probably differ enough to favor a more marked industrial development in districts 3 and 4.

Conclusions

Much work remains to be done in the field of air pollution technology before air quality considerations can be intensively applied to many community land-use programs. Once the dispersion characteristics of atmospheric pollutants are known and the ranges of tolerance for them in humans, animals, and plants are better understood, the dilution values can be analyzed jointly with the established tolerable pollution levels for various receptor areas. Such joint analysis should provide a hopefully more realistic index than is presently available for evaluating industrial district suitability in terms of over-all community planning.

It is hoped that this limited example, which is amenable to rather straightforward meteorological treatment, will encourage city planners to look further into the feasibility of integrating meteorological considerations into land-use programs for the ultimate purpose of preserving community air quality.

Acknowledgement

The author wishes to thank Francis Pooler, Jr., for his assistance in the development and final review of the paper.

Appendix A

From the following equation,[7] the long-term average concentration distribution downwind from a continuous source is determined by diffusing the effluent in the vertical only and then distributing the effluent over a sector of 45°, or $\pi/4$ radians. This sector width is the interval into which the wind directions were classified.

$$\frac{\chi}{Q}_{av} = \frac{2}{\pi^{1/2}(\pi/4)\bar{u}C_z x^{2-n/2}} \exp\left(\frac{-h^2}{C_z^2 x^{2-n}}\right)$$

where

χ = concentration (mass units per cubic meter)
Q = source strength (continuous, unit mass per second)
$\bar{u}$ = mean wind speed (meters per second)
n = stability parameter (nondimensional)[8]
C_z = generalized vertical diffusion coefficient (meters)$^{n/2}$
x = downwind centerline distance measured from a ground point beneath a continuous source (meters)
h = effective height of source (meters)

There should be no serious objection to assume anistropic diffusion conditions for the neutral and stable periods (isotropic for the unstable). Therefore, the ratios of C_y to C_z for the unstable, neutral, and stable categories may be considered to be 1, 2, and 4 respectively. The C_z values in Table I are thereby obtained by dividing the corresponding computed coefficients C_z[9] based on a method by Barad and Hilst,[10] by 1, $\sqrt{2}$, and 2.

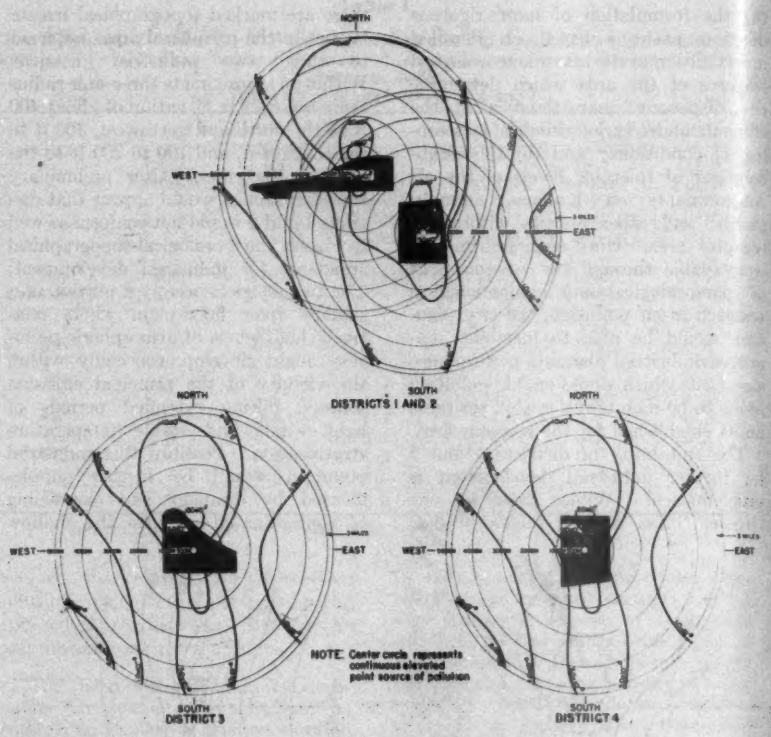

Fig. 4. Composite relative dilution patterns for various source districts.

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APCA Announces Belyea as Pres; Names Five as Board of Directors

APCA announces the 1960–61 Board of Directors and President of the Association.

President Harry A. Belyea serves as Chief Air Pollution Control Officer of Metropolitan Toronto. A graduate of the University of Toronto in M.E., Mr. Belyea also served with the following: Goodyear Tire and Rubber Company; Canadian Underwriters Association, Fire Prevention Engineer; Dominion Government War Department; Industrial Hygiene Division of the Ontario Department of Health, Ventilation Consultant.

* * *

Ralph W. Bourne, Board of Directors, is Chief Engineer, Air Pollution Control District, Jefferson County, Kentucky. Mr. Bourne is a graduate in Chemical Engineering at the University of Pittsburgh and has been associated with DuPont, Reynolds Metals Company, Louisville Soy Products, and Louisville Registered Professional Engineers. Mr. Bourne has been serving in an engineer's capacity, and became Assistant Chief Engineer and later Chief Comb. Engineer for Louisville Registered Professional Engineers.

Ralph W. Bourne

* * *

Austin N. Heller, Board of Directors, is Co-ordinator of Long Range Planning, Plastics and Coal Chemical Division, Allied Chemical Corporation in New York. Mr. Heller claims Johns Hopkins University for his Alma Mater where he received an A.B. in Chemistry.

Austin N. Heller Fred T. Mommsen

He attended graduate school at Johns Hopkins and received his M.S. in Chemical Engineering from Iowa State College. Mr. Heller has been associated with Wallace and Tiernan Company, New York University, Allied Chemical Corporation in the Industrial Wastes Development Section, Plastics and Coal Division as Supervisor. He served in the U. S. Navy as Lt. Jr. Grade and is at the present time Lt. Commander with the U.S. Naval Reserves.

Fred T. Mommsen, Board of Directors, is presently Director, Department of Air Pollution Control, City of Chicago. After receiving his degree in Combustion Engineering at Hayes Institute of Engineering, Mr. Mommsen went with the City of Chicago where he has been for 22 years, serving in the following capacities: Junior Combustion Engineer, Field Supervisor of Inspection, and Assistant Director. He also represented the APC in the drafting of the new Chicago APC Ordinance.

* * *

Louis V. Olson, Board of Directors, is Director of Water and Air Pollution Problems, American Smelting and Refining Company, Salt Lake City, Utah.

Louis V. Olson Morton Sterling

He is a graduate of Stanford University with an S.B. in Biological Chemistry and an M.S. in Metallurgy. He has been employed continuously with American Smelting and Refining in various capacities connected with stream and air pollution since 1916.

* * *

Morton Sterling, Board of Directors, serves as Chief, Bureau of Air Pollution Control, Detroit. He earned his B.M.E. at Polytechnic Institute of Brooklyn, and has worked with Brown Products Company, Morse Boulger, Ford Motor Company, and is an Instructor in the Mechanical Engineering Department, Lawrence Institute of Technology.

CLASSIFIED

AIR POLLUTION CONTROL OFFICER position available in the City of Lorain, Ohio. Salary open. Address request for application to Director of Public Services, City Hall, Lorain, Ohio.

SUPREME COURT UPHOLDS LAW IN DETROIT CASE

The Supreme Court recently upheld Detroit's anti-smoke ordinance of 1947 as applied to Great Lakes ships docked at the City piers.

The ordinance was challenged by the Huron Portland Cement Co., which operates a fleet of four steamships.

The Company sued to bar enforcement of the smoke abatement code after it had been haled into court for violations in 1955.

Huron argued that the anti-smoke requirement interfered with interstate commerce. It pointed out that it is licensed by the Treasury Department to carry on coasting and foreign trade.

The Supreme Court of Michigan ruled on Jan. 12, 1959, that the ordinance was no more than a "reasonable exercise of local police power."

This decision was affirmed seven to two by the Federal Supreme Court.

Reducing Emissions

(*Continued from page 207*)

Chromatography for Identifying Air Pollutants," *Science*, 120, 662–3 (1954).
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Method for Evaluation

(*Continued from page 221*)

Acknowledgments

Very few contributions today are performed by a single author. I would like to thank the following individuals for their contributions and discussions: Kenneth Downes and Maynard E. Smith of the B. N. L. staff and Max Woodbury of New York University.

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★ ★ ★ Section Hi-Lights ★ ★ ★

East Central Section

The East Central Section is now in the process of planning its annual meeting which is to be held Sept. 22–23, 1960, in Detroit, Mich. The tentative program which has been issued indicates the meeting will be an interesting and informative one.

Topics which are included for discussion are: Trends in Air Pollution Legislation, The Air Pollution Control Team (related to incineration of industrial wastes), Psychology of an Enforcement Program, New Techniques for Solving Some Unique Air Pollution Problems, The Present Status of Research on Air Pollution Health Relationships, Industrial Uses of Radioactivity and Its Control.

In addition, such interesting subjects as Current Status and Future Work on Vehicle Emission Control Devices and Carbon Monoxide as an Air Pollutant—A Factor in Traffic Accident Causation? will be presented. Arnold Arch, executive secretary of APCA, will be the luncheon speaker on the second day.

The ESC wishes to announce that the authors of papers and participants in the panel discussion at their 1959 annual meeting, Youngstown, Ohio, will answer inquiries regarding their contributions to this meeting. No formal proceedings will be published of this meeting. However, authors may be able to supply those people interested with copies of their papers. A list of the topics and authors follows.

Steel Mill Problems . . . . **Granville A. Howell,** Project Development Engineer, U. S. Steel Corp., Pittsburgh, Pa.

Case Histories . . . . . **Alfred L. Kiewit,** Director of Engineering, Coal Producer's Committee for Smoke Abatement, Cincinnati, Ohio

Pollen as a Factor in Air Pollution . . . . . **Samuel R. Zoss, M.D.,** Youngstown Representative, Pollen Collecting Committee of the American Academy of Allergy, Youngstown, Ohio

Mechanically Wired Dust Collector . . . . **Seymour Calvert,** Associate Prof. of Chemical Engineering, Case Institute of Technology, Cleveland, Ohio

Photochemically Initiated Oxidations . . . . . **Jack G. Calvert,** Associate Prof. of Chemistry, Ohio State University, Columbus, Ohio

Incinerators to Meet ASA Requirements . . . . **Richard B. Engdahl,** Division Chief of Thermal Engineering, Battelle Memorial Institute, Columbus, Ohio

Training in Air Pollution Technology . . . . **James P. Sheehy,** Assistant Director of Air Pollution Training Program, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio

Instrumentation for Particulate Sampling . . . . **Joseph E. Zatek,** Technical Products Engineer, Mine Safety Appliances Co., Pittsburgh, Pa.

Panel Discussion Participants:

Bernard A. Dawson, Smoke Control Co-ordinator, Division of Smoke Regulation, Zanesville, Ohio

John L. Hodges, Chief of Smoke Abatement Bureau, Division of Air and Stream Pollution, Cleveland, Ohio

Richard D. Shafer, Chief Smoke Regulation Engineer, Division of Smoke Regulation and Inspection, Columbus, Ohio

Morton Sterling, Chief Air Pollution Inspector, Bureau of Smoke Inspection and Abatement, Detroit, Mich.

Topics:

A Visual Determination of Air Pollution

Reducing the Visible to a Reasonable Level

Sampling the Atmosphere for the Invisible

A Divisible Control of the Invisible

West Coast Section

The Los Angeles local group of the West Coast Section held a dinner meeting in April after which UCLA's smog research program was discussed. A guided tour of the University's air reaction tunnel, especially designed for eye irritation studies, followed the dinner. The program was presented by Harry Buchberg, M.S., environmental control specialist; Kenneth Lindh, M.S., design engineer; Katherine Wilson, Ph.D., expert in air pollution chemistry; and Margaret Jones, Ph.D., psychologist who has done appreciable work in psychophysics.

In Memoriam . . .

I. E. Shaer, of the I. Ernest Shaer Co., Brookline, Mass., died November 29, 1959.

George A. Patterson, Founder of Niagara Frontier Section, passed away, May 15, 1960.

Personalia

Dr. E. M. Adams of Dow Chemical Co., Midland, Mich., has been elected chairman of the Manufacturing Chemists' Association's Air Pollution Abatement Committee.

He succeeds A. B. Pettit of W. R. Grace & Co., New York City.

O. C. Thompson of Union Carbide Corp., South Charleston, W. Va., is the new vice chairman, succeeding Elmer P. Wheeler of Monsanto Chemical Co., St. Louis, Mo. Mr. Thompson serves also as chairman of the Association's Water Pollution Abatement Committee.

The chairman and vice chairman are elected for two-year terms.

The 88-year-old MCA represents more than 90 percent of the chemical production capacity in the U. S. Its Air Pollution Abatement Committee was formed in 1949 to disseminate information designed to help the industry with its air pollution problems.

* * *

Eugene F. Scherr was named manager of the midwest territory for Western Precipitation Division, Joy Manufacturing Co.

With 15 years service in the Chicago office Red Scherr is well known in industry throughout the midwest. A graduate engineer, he will be in charge of all company operations for dust and fume control equipment.

* * *

Howard W. Lange has been promoted to manager of the western Territory of Western Precipitation Division of Joy Manufacturing Co. with headquarters in San Francisco, according to R. F. Stewart, Vice President of Western Precipitation.

Welcome New Members

(*Continued from page 180*)

Turner, Donald E.
Salt Lake City, Utah

Venezia, Ronald A.
Grand Island, New York

Weaver, Everett F.
Pasadena, Texas

Willett, Howard P.
New York, New York

Wilson, Thomas F.
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53RD ANNUAL MEETING SETS NEW GOALS FOR '61

The 53rd Annual Meeting of APCA in Cincinnati, Ohio, was concluded with a near-record attendance of 623 scientists, researchers, doctors, engineers and representatives of Federal, state and local governmental agencies.

The Association has set its sites on achieving two goals within the coming year; increased collaboration with foreign countries and a U. S. membership gain of about 50%.

President Harry A. Belyea, Chief Air Pollution Control Officer of Metropolitan Toronto, Canada, reports that the presence of a sizable number of foreign representatives indicated that during the next year collaboration with countries abroad will become an important aspect of APCA activities.

Emphasizing that "all forms of air pollution will continue to be APCA's targets," Mr. Belyea said, "from all appearances, however, automotive exhaust research again will get a lot of attention."

Various technical papers presented at the 53rd meeting dealt with this problem which many experts regard as the number-one pollution challenge in the nation.

Another important step authorized by the board was the decision to increase publication of the *APCA Journal* to one issue monthly instead of bi-monthly, as soon as advertising revenue justifys it.

Also on schedule before APCA holds its 1961 meeting in New York probably will be the establishment of closer relations with Mexico and the expansion of air pollution programs in Canada.

INFORMATIVE REPORT

(*Continued from page 218*)

9. "The Making, Shaping and Treating of Steel," 6th Ed., U. S. Steel Company (1951).
10. The Making, Shaping and Treating of Steel, U. S. Steel Corp., 7th Ed., p. 338 (April, 1957).
11. Allegheny County Bureau of Smoke Control, Ninth Annual Report of Activities; Appendix 1. Steel and Allied Industries Joint Smoke Control Research Committee (May 31, 1958).

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H. E. Rowen, P. V. Gallagher, and T. E. Ban, "Something New in Sintering," *Iron & Steel Eng.*, 133–144 (August, 1957).
Anon., "Weirton Operating New Sintering Plant," *Iron & Steel Eng.* 165, (August, 1958).
Anon., "J & L Installs Sintering Plant at Otis Works," *Iron & Steel Eng.*, 174 (March, 1958).
W. V. Packard, "Steel Industry Cinderella, *Steelways* 5–7 (December, 1957).

Identical Bills Concerning Air Pollution Are Introduced in Senate and House

Identical bills were introduced recently into the Senate and House of Representatives which provide for public hearings on air pollution problems of more than local significance, and extend the duration of the Federal air pollution control law.

Senate Bill 3108 and H. R. 10696 propose amendments to the Act of July 14, 1955, (42 U.S.C. 1857b). The major amendment consists of a new Section 6 which would read as follows:

"(a) Whenever, on the basis of reports, surveys, or studies, he believes it appropriate, or whenever requested by any State or local government air pollution control agency, the Surgeon General may call a public hearing on any problem of air pollution which may affect or be of concern to communities in various parts of the Nation or which may affect any community or communities in any State other than the State in which the matter causing or contributing to the pollution originates. Any such hearing shall be conducted before a board composed of not less than five members, appointed by the Secretary of Health, Education, and Welfare, who will be representative of the public, industry which is affected by or concerned with the problem, persons who are expert or have special knowledge in the matter, interested Federal agencies, and interested State or local government air pollution control agencies.

"(b) Subject to regulations of the Surgeon General, an opportunity to be heard at such hearing shall be accorded to all interested persons.

"(c) After consideration of the information presented at the hearing and such other information as is available to it, the board shall make a report and recommendations to the Surgeon General on such matters as the existence, cause, and effect of the air pollution on which the hearing was held, progress toward its abatement, and other related matters. Such reports and recommendations, together with the comments and recommendations, if any, of the Surgeon General with respect thereto, shall be available to the community or communities, Government agencies, and industries concerned, and to the extent the Surgeon General deems appropriate, to the public, but shall not be binding on any person, agency, or organization."

Public Health Survey Made on USSR AP Lit

A survey of USSR literature on air pollution and related occupational diseases is being conducted by Dr. Ben S. Levine under a U. S. Public Health Service research grant. The first volume in the survey has been released for sale to the public by the Office of Technical Service, Business and Defense Services Administration, U. S. Department of Commerce.

Doctor Levine's survey is primarily for the benefit of the English-speaking scientist who wants information on Russian air pollution research. The survey covers the basic concepts of air pollution prevention in the USSR.

Previous volumes of Russian air pollution studies condensed and translated by Doctor Levine for the PHS include:

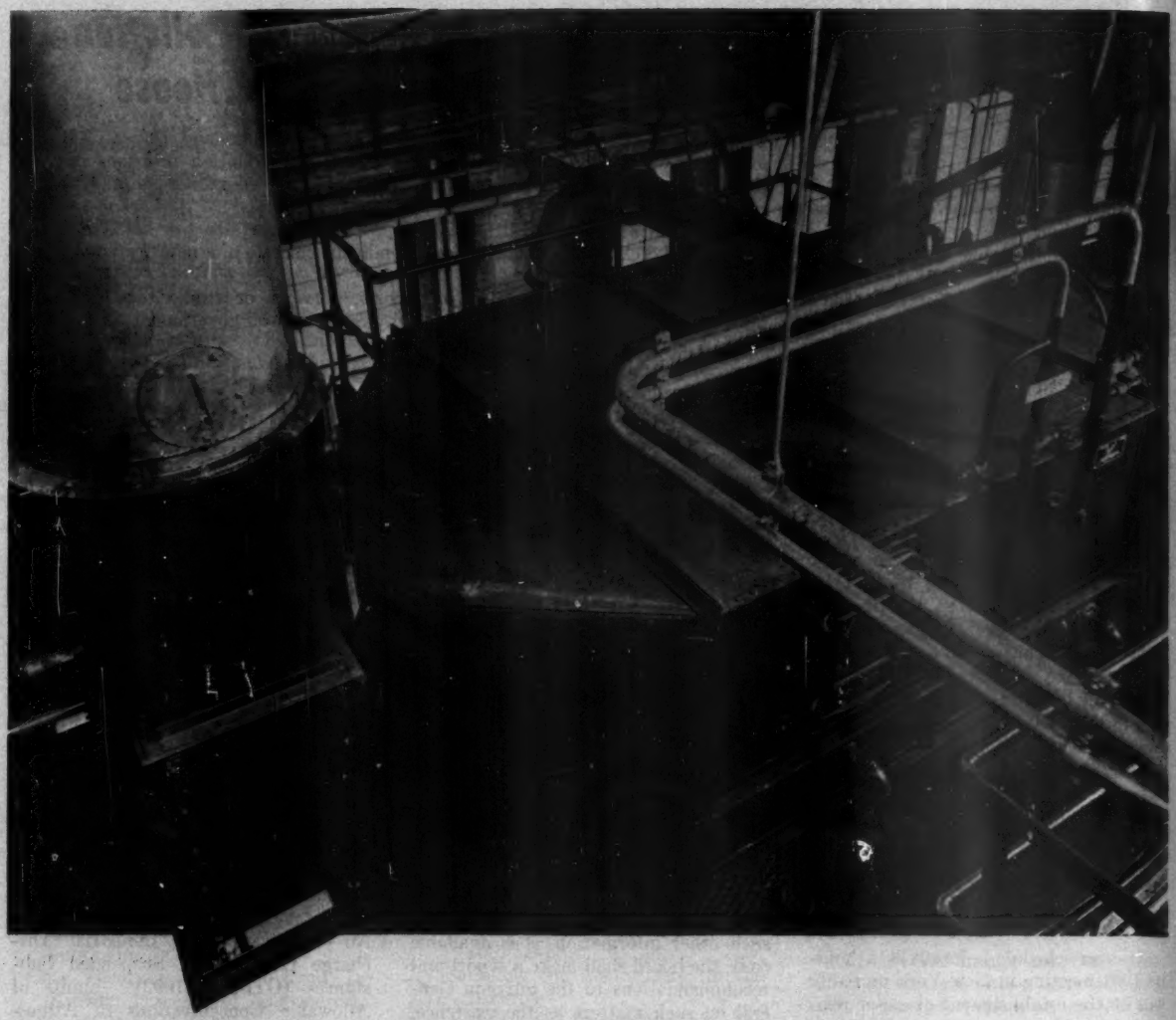
Sanitary Protection of Atmospheric Air—Purification of Industrial Discharge Gases From Suspended Substances (OTS 59–21092). Limits of Allowable Concentrations of Atmospheric Pollutants (Book 1—OTS 59–21173, Book 2—OTS 59–21174, Book 3—OTS 59–21175).

The initial volume of the newest survey series is:

USSR Literature on Air Pollution and Related Occupational Diseases, Volume 1, B. S. Levine, Ph.D., U. S. Public Health Service, Department of Health, Education, and Welfare research grantee, 214 pages, (Jan., 1960). (Order OTS 60–21049 from OTS, U. S. Department of Commerce, Washington 25, D. C., $3.50.)

CALENDAR

June 12–17	Electrical Precipitation Seminar, Department of Electrical Engineering and Continuing Education, Pennsylvania State University, University Park, Pa.
July 25–29	13th International Congress on Occupational Health, Waldorf-Astoria Hotel, New York City.
Sept. 22–23	East Central Section Annual Meeting, Detroit, Mich.
Nov. 17	Mid-Atlantic States Section Meeting, Consolidated Edison Co., New York, New York.



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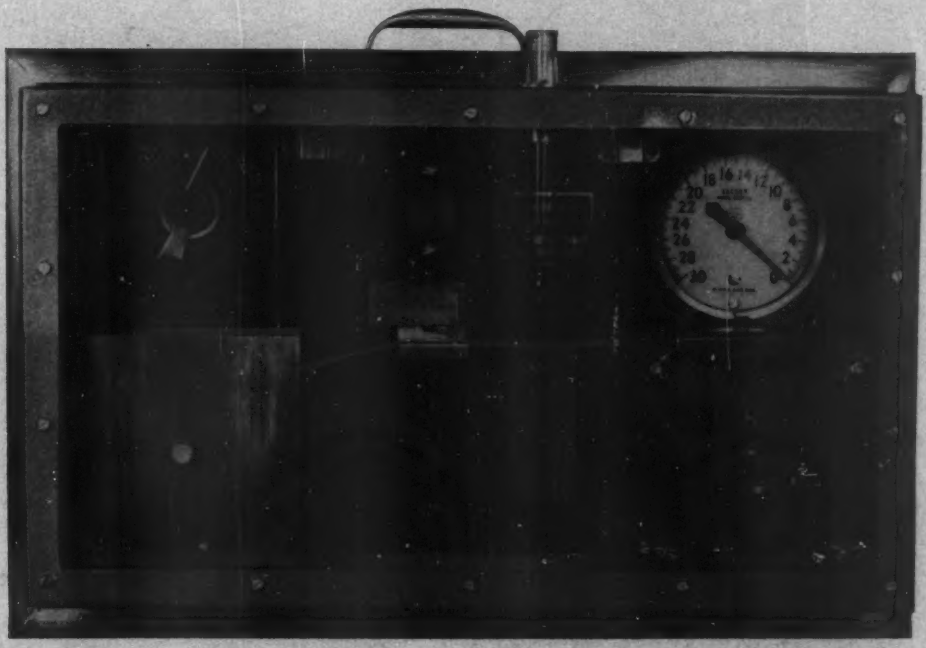

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*Patterned after sampler developed by the Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio, and described in Nader, J.S.: "A Versatile, High Flowrate Tape Sampler," JAPCA, Vol. 9, No. 1, May 1959

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FOR A HEALTHIER ENVIRONMENT THROUGH MODERN CHEMISTRY

This is one of a series of ads which Gulf has addressed to those who write and edit the news. It is reprinted here as a service of information.

GULF PRESS CONFERENCE 8

A service of Gulf Oil Corporation in the cause of creating—through the facts as we see them—a fuller understanding of the oil industry.

Clean Air: Whose Responsibility?

There are so many things that make life simpler for us these days. Yet some of these very conveniences produce undesirable by-products in the form of industrial and automotive exhaust. How can we dispose of these wastes without contaminating the air we breathe? That is the problem of air pollution control. Science and good judgment have given us some answers. As industry and individuals, how far do we still have to go?

Q. Why bring in the individual? Isn't he victim, not culprit, in the smog problem?

A. To a degree he is both. Take any smoking home furnace, trash pile, or car engine in need of tuning. Multiply the volume of improperly burned fumes by the number of such offenders and you have trouble-sources that offset any gains made by industry.

Q. What is industry doing on its part to keep the air clean?

A. Industry is spending hundreds of millions a year to control and eliminate contaminants formerly discharged into the air. As for Oil, the American Petroleum Institute has spent—in research, alone—$1.3 million on 14 major projects. And in a recent three-year period individual oil companies have put in more than $66 million worth of equipment to avoid polluting air in communities where they operate. These companies spend $1 million a year more in continuing research. As you see, clean air costs money.

Q. Can you point to practical results from these expenditures?

A. Yes, and they often extend well beyond clean air. Take just one factor in air pollution: the sulfur compounds in a plume of smoke. In Los Angeles, where the smog problem is most acute, refiners have spent $6 million to eliminate sulfur from refinery exhaust. Six hundred tons a day of these waste gases are now converted to useful by-products. So clean air can be good business another way. It can sometimes pay its own way.

Q. Should control measures have to pay their own way?

A. Not at all. Most control practices are extra expense which industry undertakes in living up to its community responsibility. Let's list what refiners have done to conserve clean air. *Odor elimination:* they've exploded the notion that refineries have to smell bad. *Smoke control:* through reduction of emergency flaring to absolute minimum and smokeless burning, they've eliminated the refinery as a significant source of trouble. *Evaporation control:* they've cut escape of contaminants from that source by 70%.

Q. You suggested the motorist can help control exhaust from his own car. How much pollution does car exhaust account for?

A. In New York City, automobiles pump out 10,000 gallons of unburned gasoline into the air every hour. In Los Angeles, they pour about 2,450 tons of smog-producing materials into the air every day. It is now agreed by competent scientists that automobile exhaust is the principal source of air pollution in Los Angeles.

Q. What about gasoline that's fully burned? How much pollution does it account for?

A. If gasoline could be fully burned in an automobile engine, no serious contaminants would be produced. But that engine—especially when in poor repair—emits some partially burned materials. In the presence of ordinary sunlight these emissions undergo the chemical change that makes smog.

Q. Can't the oil industry produce a gasoline without smog-causing materials?

A. Nothing would please the oil industry more than to develop a truly "smogless gasoline." But despite much costly research, there isn't such a gasoline known today nor is it considered likely that one will be developed in the future.

Q. How is the car maker living up to the responsibility for keeping the air clean?

A. Manufacturers are making a practical start at solving the problem in their 1961 models. They have already spent $6 million on basically two approaches. One would send pollutants that now escape from the carburetor and crankcase back into the engine for burning. The other would clean up partially burned gases that get as far as the tailpipe. The auto industry agrees to share patents on whatever device proves most efficient.

Q. What can the individual car owner do to cut down on smog now?

A. He must make sure his engine is tuned. It will cost him about $25 to $30 a year. Yes, smog control costs money. But it is estimated a well-maintained car puts 60% less pollution into the air (and uses 15% to 20% less gasoline) than a car with dirty plugs, a too-rich fuel mixture, improper timing and faulty rings. Such cars would reduce smog enough to satisfy control officials of almost any city.

Q. Are you saying different cities have different control requirements?

A. Yes. Cities have different atmospheric conditions affecting smog formation. In Los Angeles, ventilation is poor, and the abundance of sunlight plays havoc, as we said, with exhausts. There, almost total control is required. But other cities have better natural dispersal of exhausts. Controls satisfactory to one community should not be adopted as the "easy way out" of smog contamination elsewhere.

Q. Isn't it true that this contamination may become a serious health hazard if allowed to get worse?

A. We can't ignore any irritant as a health hazard. Public health officials and industry doctors are accumulating considerable data, but not sufficient to relate air pollution to disease. That is not to say we have reason for complacency. It is up to all of us to remove smog as a possible threat to health.

We welcome further questions and comment. Please address them to Gulf Oil Corp., Room 1300, Gulf Bldg., Pittsburgh 30, Pa.

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